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Military topography for the mobile forces

Clarence Osborne Sherrill, United States. Army Service Schools (Fort Leavenworth, Kan.), United ...

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MILITARY TOPOGRAPHY
FOR THE MOBILE FORCES

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MILITARY TOPOGRAPHY FOR THE MOBILE FORCES

INCLUDING

MAP READING, SURVEYING AND SKETCHING

WITH MORE THAN 175 ILLUSTRATIONS AND ONE MAP OF VICINITY OF FORT LEAVENWORTH

BY

CAPTAIN C. O. SHERRILL

CORPS OF ENGINEERS, U. S. ARMY

INSTRUCTOR IN THE DEPARTMENT OF ENGINEERING

U. S. SERVICE SCHOOLS

FORT LEAVENWORTH, KANSAS

FOURTH EDITION

SEVENTH THOUSAND

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MILITARY TOPOGRAPHY FOR THE MOBILE LAND FORCES.

PREFACE.

1. *The ability to read a map* and to comprehend the military possibilities of the terrain is now recognized by all military authorities as an absolute essential for all officers who hope to be efficient in time of war. General Kuropatkin, who commanded the Russian forces in the recent Russo-Japanese War, says: "A regimental commander could not, as a rule, read a map himself, much less teach those under him how to do so. This was especially the case at the beginning of the war, and had considerable influence on the conduct of operations, as regiments often arrived late at their rendezvous or went to points where they were not wanted."

2. It is further recognized that one of the best methods of learning, in time of peace, how to handle troops in time of war is by solving map problems* and by playing war games (map maneuvers). These methods are much used in all leading foreign armies and have been adopted by our own Regular Army, Marine Corps, and by some of the National Guard organizations, always with the great-

*The student is advised to read "Tactical Solutions and Problems" by Capt. M. E. Hanna, 3d. Cavalry.

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est success. But to solve these problems the first requirement is the ability to read, quickly and accurately, a contoured military map.

8. Lt. General Litzman, Commandant of the German Staff College in his work on the solution of Tactical Problems forcibly emphasizes the same idea and lays especial stress on the advantage derived, in solving tactical problems, by practical work in topography. He says: "A practical solution can nearly always be found by him who has sufficient talent and experience to see the map plastically before him and not only to comprehend mechanically the information in the problem concerning both forces but actually to see the opposing parties with his mind's eye and, as it were, actually experience the events portrayed.

The necessary basis for the solution of problems, therefore, is a correct comprehension of the map and of the opposing forces. The map lies before the solver; he only needs to be able to read it; this does not mean merely that he must be able to understand the meaning of all conventional signs and to reckon distances, but also that he must be able to comprehend all details so that they form themselves into a complete and harmonious whole, and this to such an extent that he actually feels the nature of the terrain in the map before him. Every soldier who is at all fitted for the duties of leadership can, by practice, gain this ability, though the time required may be long or short, according to the natural ability of the worker. The frequent compari-

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son of the map with actual terrain conditions is particularly helpful. * * * * * For him who has been for a few years engaged in topographical work (in representing nature on the map), the reverse operation of understanding actual terrain from the map will be especially easy."

4. This book has been written with the intention of giving to line officers of the Mobile Land Forces the principles and methods of making and using military maps and sketches necessary for a complete mastery of the military possibilities of ground and maps. With this special object in view, all difficult mathematical discussions and obsolete or unnecessary surveying instruments are omitted, and only those subjects are treated which should be thoroughly understood both theoretically and practically by every officer. The end in view is not only to give instruction in rapidly making good topographical maps and sketches under service conditions; but *especially to assist officers in acquiring that trained topographical eye which grasps instantly the possibilities and limitations of the terrain in its influence on the military situation.*

5. *The object of Part I, Military Map Reading,** is to give a statement of the principles and a solution of the problems essential to the accurate and rapid use of maps for military purposes, such as tactical map problems, war games, and maneuvers. The treatment has been made as simple as

*A revised and enlarged edition of the book "Military Map Reading" of which 10,000 copies were sold.

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possible, but the ground is covered fully in order to provide a complete reference book on Military Map Reading. There are a large number of problems and their solutions given, but these have been *limited to such as have practical military utility* to prevent an erroneous idea of the possibilities and limitations of maps.

6. *Part II, Military Surveying,* lays especial stress on the use of the plane table and stadia method, as *the best means of acquiring skill in accurately estimating distances, slopes, and elevations.*

7. *Part III, Military Sketching,* gives in detail the methods used at the Army Service Schools in rapid military sketching, illustrated by a detailed study of the steps followed in particular sketches. Especial emphasis is laid on practical methods of estimating distances, horizontal angles, slopes and elevations; and each detailed step in the work has been explained carefully, for the benefit of those learning to sketch without the guidance of an instructor.

8. Messrs. Keuffel and Esser kindly furnished a large number of plates of their instruments, for which the author is duly appreciative.

Acknowledgment is made to the Chief of Engineers for permission to make use of matter from the "Engineer Field Manual"; to the Superintendent Smithsonian Institute for tables; to Messrs. Pence and Ketchum for permission to refer to their excellent "Surveying Manual."

The Author acknowledges his obligations to M.

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To Major E. R. Stuart, Captain J. A. Woodruff, Captain A. W. Bjornstad, Lieut. Geo. C. Marshall, Jr., and Lieut. R. E. Beebe, U. S. Army, especial acknowledgment is made for suggestions and criticisms.

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LIST OF BOOKS CONSULTED.

Engineer Field Manual.
Military Topography, Larned.
Topographical Surveying and Sketching, Rees.
Military Topography and Sketching, Root.
Catalogue, Keuffel and Esser.
Text Book of Military Topography, Richards.
Pamphlet on Conventional Signs, War Department.
Field Service Regulations.
Infantry Firing Regulations.
Military Topography, Verner.
Elements of Military Topography, Demangel.
Manual of Field Sketching and Reconnaissance.
Engineers' Surveying Instruments, Baker.
Surveying Manual, Pence and Ketchum.

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INTRODUCTION.

GENERAL PRINCIPLES.

1. By the term *"Military Topography"* is meant the various features of ground important in military operations, and the principles governing the study and methods of representing these features. The subject of Military Topography naturally divides itself into three parts, *Military Map Reading, Military Topographical Surveying, Military Topographical Sketching.*

2. *Military Map Reading* treats of the nature of maps, of the objects represented on maps, their military uses and the methods of interpreting them.

3. *Military Topographical Surveying* treats of the means and methods used in making military topographical maps with instruments of precision.

4. *Military Topographical Sketching* treats of the means and methods used in making Military Road and Area sketches, and the reports on the topographical features thereof.

5. *Military Map Reading* is considered first because a general knowledge of the meaning of maps and sketches, of the information conveyed by them, and of the military uses to which they may be applied, is essential before an intelligent idea can be obtained of the necessary features to be represented thereon.

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Military Surveying is treated next, because of the necessity of studying, in detail, ground forms in comparison with their map representations as a preliminary foundation for the perfect knowledge of maps and ground required by military men. This study should be prosecuted with the assistance of surveying instruments of precision, in order that the student's ideas of horizontal distances, differences of elevation, slopes, and shapes of all kinds of ground forms may be immediately checked and corrected on the spot by the readings on the instrument. There is no other method of learning to estimate distance (so important in battle firing, scouting, ranging etc.) which can compare with the study of surveying and sketching. The same is true of learning to estimate every other relation found on the ground such as the cover possible for an attacking line, the strong points of a position, etc. The artilleryman may know his gun fire will just graze a slope of so many degrees, but he will have no idea what that particular slope looks like on the ground if he has not had some correct means of measuring such slopes until he can accurately estimate them.

6. *Military Topographical Sketching* is considered last because the basic principles of topography must first be learned by the study of surveying with the exact instruments as a constant guide and check on every estimate made of ground forms, before a sufficient grasp and comprehension of ground is secured by the student to enable him to make military sketches truly representing features before him with the rapidity required by the military service. *No*

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man can become an excellent sketcher until he involuntarily sees the map forms which would correspond to the ground observed; nor can he be a perfect map reader or scout until to see a map is at once to picture to himself intuitively the ground form from which the map is made. A conscientious study and application of the subjects treated herein will give the average military man the topographical knowledge and the training of the eye essential to every soldier. It is to be remembered that the final end of the study of Surveying and Sketching is not alone to become proficient in these two subjects but also to learn everything about the military features of ground and their representation on maps, as a basis for the accurate and prompt solution of all military problems.

7. Not every officer has *facility for making maps and sketches,* and consequently there are some who cannot hope to become experts in this work; yet this fact should not deter any one from the study of this subject, because of the military knowledge thereby obtained. However, facility in handling a pencil is of small importance, as is witnessed by scores of poor draftsmen who have become excellent sketchers, able to show clearly and accurately the essential military features of the area sketched; but *the facility that is required* for learning to represent ground forms correctly, is the *facility for mastering the details of these forms.* This knowledge of ground is an absolute essential in every military operation, and officers deficient in it, who would become great tacticians or strategists, must

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learn by patient effort that which very few know intuitively—the relation between ground and its corresponding map.

8. The *subjects discussed* in this book are strictly limited to those required by officers of the Mobile Land Forces in securing the topographical knowledge demanded by the modern Art of War; and the treatment is made as simple and as free from mathematics as possible while fully covering the subject.

9. *Geodetic methods are not considered,* for the reason that not one Line officer in a hundred will ever be called on to make a geodetic survey; but all officers must have a good grasp of topography to excell in the military profession. Those officers who may be called on to make a geodetic survey should provide themselves with a good work on general surveying such as Johnson's or Wilson's.

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MILITARY MAP READING.

CHAPTER I.

CLASSES OF MAPS.

10. *Maps* are representations to scale (usually on a plane) of portions of the earth's surface. They are of various kinds, depending on the use for which they are intended, and may or may not represent relative heights as well as horizontal distances and directions. For instance, the ordinary County Map shows only roads, boundaries, streams and dwellings. *A Topographical Map* shows the horizontal relation of points and objects on the ground represented and in addition gives the data from which the character of the surface becomes known with respect to relative heights and depressions.

11. Suppose an officer is sent out by his commander in unknown country to pick out a good position for camp and outpost, and to report upon his return the military features of the site selected. On visiting the ground selected his eye can only take in a very limited portion from any one position, and even with the most careful examination from various points he would get only a very general idea of the larger features. But if on returning he tries to

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describe in words to his commander the position selected, he would find his task almost impossible. The simplest sketch, however, made by him on the ground, even if not correct as to scale or elevations, would enable him to give his commander as good an idea as he had himself obtained; but a report based on an accurate map or sketch would be full and complete. It is almost impossible to organize and carry out marches, reconnaissances, concentrations, etc., without maps upon which to base the orders.

12. Almost all classes of maps have some military uses. For example, an ordinary map showing the location of important towns, large rivers, and roads, is useful for arranging the concentration of large bodies of troops or for following the operations of a campaign, but it is far from being in sufficient detail for the purposes of those who plan or study the smaller operations of war. A complete military map, on the contrary, must give both the horizontal and vertical relations of the ground and also a representation of all military features of the area.

A Military Map, therefore, is one which gives the relative distances, elevations, and directions of all objects of military importance in the area represented.

MAP READING.

13. By Map Reading is meant the ability to grasp by careful study not only the general features of the map, but to form a clear conception or mental picture of the appearance of the ground represented. This involves the ability to convert map distan-

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ces quickly to the corresponding ground distances; to get a correct idea of the network of streams, roads, heights, slopes, and all forms of military cover and obstacles. The first essential therefore, for map reading is a thorough knowledge of the scales of maps.

SCALES OF MAPS.

14. A map is drawn to scale—that is, each unit of distance on the map must bear a fixed proportion to the corresponding distance on the ground. If one inch on the map equals one mile (63360 inches) on the ground, then $\frac{1}{3}$ inch equals $\frac{1}{3}$ mile, or $63360 \div 3 = 21120$ inches on the ground, etc. The term *"Distance"* in this book is taken to mean horizontal distance; vertical distance to any point is called elevation or depression, depending on whether this point is higher or lower than the one from which the measurements are made. For example, the distance from Frenchman in a straight line to McGuire (Leavenworth Map) is 2075 yards, but to walk this distance direct would require the ascent and descent of Sentinel Hill, so that the actual length of travel would be considerably greater than the horizontal distance between the two points.

In speaking of distance between towns, cities, etc., horizontal distance is always meant. In referring to such distances, that by the shortest main road is usually intended. For example, from Fort Leavenworth to Kickapoo (Leavenworth Map) is 5 miles, measured over the 5-17-47 road. The fixed ratio (called the scale of the map) between distan-

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ces on the map and the corresponding distances on the ground should be constantly kept in mind.

METHODS OF REPRESENTING SCALES.

15. There are three ways in which the scale of the map may be represented:

1st. *By an expression in words and figures;* as 3 inches=1 mile; 1 inch=200 feet.

2d. *By what is called the natural scale or the Representative Fraction* (abbreviated R. F.), which is the fraction whose numerator represents units of distance on the map and whose denominator represents units of horizontal distance on the ground, being written thus: R. F. $\frac{1 \text{ inch}}{1 \text{ mile}}$, $\frac{1}{63360}$, 1:63360, or 1 is to 63360,—all of which are equivalent expressions, and are to be understood thus: $\frac{\text{Map}}{\text{Ground}}$ that is the numerator is distance on the map, the denominator is horizontal distance on the ground. This fraction is usually written with a numerator of unity, no definite length of unit being specified in numerator or denominator. In this case, the expression means that one unit of distance on the map equals as many of the same horizontal units of distance on the ground as there are units in the denominator.

The R. F. is synonymous with the term scale of the map. Therefore, if the scale be changed the R. F. will be changed in exactly the same manner and amount. To increase the R. F., (being a fraction), its denominator is decreased. For the same

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reason the greater the distance on the ground represented by an inch on the map, the smaller is the scale of the map. The greater the dimensions of a map to represent a given area *the larger is the scale* (that is R. F.) and the smaller the *denominator* of the latter.

3rd. *By what is called a Graphical Scale.* A Graphical Scale is a line drawn on the map, divided into equal parts, each division being marked, not with its actual length, but with the distance which it represents on the ground, (see figure 1. and Leavenworth Map).

Every map should have a graphical scale because this gives true readings no matter how the size of the map is changed in reproduction or due to weather conditions; whereas the R. F. and the number of inches per mile placed on the original map are no longer true if the size is altered. The R. F. is important, however, because it is intelligible to persons unfamiliar with the units of distance used in making the map. An expression of the scale in words and figures is also valuable because rapid mental estimates can be made of the distance between points on the ground by estimating the number of inches between these points on the map.

16. Graphical Scales are of two kinds depending on the purpose for which they are constructed: (1) *Working Scales* and (2) *Reading Scales.*

A Working Scale is used in making a sketch or map and shows graphically the value of tens, hundreds, etc. of the units of distance used in making

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the map or sketch. For example, if distances were measured by counting strides or taking the time of a horse trotting, in making a sketch, then it would be necessary to construct a scale of strides or minutes of horse's trot on the desired scale of the sketch. This enables you to lay off on the sketch distances, measured thus, directly from the working scale without the necessity of calculating at each halt how many inches on the sketch are equal to the number of strides or minutes, passed over.

A Reading Scale shows the distance on the map corresponding to even tens, hundreds etc. of some convenient and well known unit of measure, such as the foot, yard, mile. For example, figure 2 shows a reading scale of yards, reading to hundreds on the *Main Scale,* and to 25 yards on the *Extension* (see fig. 1). A scale may be both a working and a reading scale when the unit of measure used in making the map is a well known length such as the foot, or yard. A reading scale in the units of one country often will not be satisfactory for use by persons of a different nationality, because of their unfamiliarity with the length of units of distance used. An officer coming into possession of such a map would be unable to get a correct idea of the distances between points represented. He would find it necessary to convert the scale into familiar units as yards or miles, see problem 4, par. 19.

It will readily be seen that a map's scale must be known in order to have a correct idea of distan-

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Graphical Scale.

Fig. 1

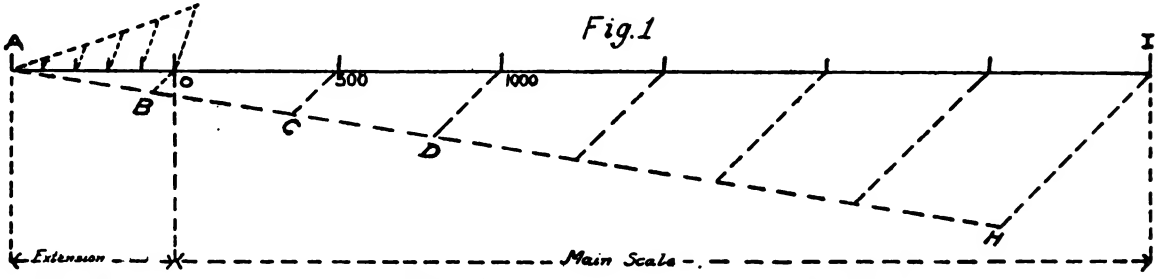

Fig. 2

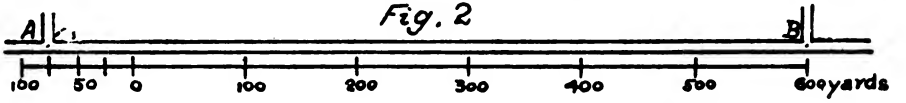

Fig 4

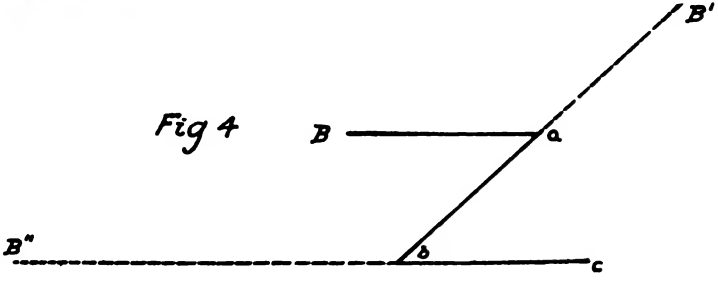

Fig. 3

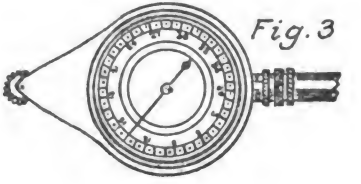

Plate 1.

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ces between objects represented on the map. This is essential in determining lengths of march, ranges of small arms and artillery, relative length of marches by different roads, etc. Therefore, if under service conditions you should have a map without a scale or one expressed in unfamiliar units, you would first of all be compelled to construct a graphical scale to read yards, miles etc., or one showing how many miles one inch represents. Or, if you were required to make a sketch by pacing, it would be necessary to construct your scale of paces on the proper R. F.

CONSTRUCTION OF SCALES.*

In the construction of scales the following are the steps taken:

(1). Find from the given data the R. F. of the map; (2) the length in inches of the unit of measure used, as pace, chain, rate of horse's trot, yard, mile etc.; (3) the number of the units of measure corresponding to one inch on the map; and (4) the length in inches on the map corresponding to an even number of tens etc. of these units of distance.

*The following relations are constantly used and should be familiar to every one:

1 mile=63360 inches=5280 feet=1760 yards.

R. F. $\frac{1}{63360}$=Scale 1 inch to 1 mile.

R. F. $\frac{1}{21120}$=Scale 3 inches to 1 mile.

R. F. $\frac{1}{10560}$=Scale 6 inches to 1 mile.

In the scale problems, units of distance on the ground will be indicated by small CAPITALS, where any confusion may exist.

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SCALE PROBLEMS.

HAVING GIVEN THE R. F.

19. Problem 1. Assume R. F. $\frac{1}{21120}$. (a) To find the value of one inch on the map in miles on the ground. Solution: If one inch on the map represents 21120 inches on the ground, then one inch (on the map), will represent as many MILES (on the ground) as one mile (=63360 inches) is contained in 21120 inches. 21120÷63360=$\frac{1}{3}$, or one inch=$\frac{1}{3}$ MILE is the scale of the map, usually expressed thus: 3 inches=1 MILE.

(b) To construct a graphical scale of yards. Solution: If one inch=21120 INCHES, then one inch=21120÷36=586.66 YARDS. Now suppose a scale about 6 inches long is desired. 6 inches=6×586.66=3519.96 YARDS, so that in order to get as nearly a six inch scale as possible to represent even hundreds of YARDS, assume 3500 YARDS to be the total number to be represented by the scale. The question is then, how many inches are necessary to show 3500 YARDS. Since 1 inch=586.66 YARDS, as many inches are necessary to show 3500 as 586.66 is contained in 3500 YARDS, or 3500÷586.66=5.96 inches. Now lay off with scale of equal parts A I, figure 1,=5.96 inches (5 inches+48 50ths) and divide it into 7 equal parts by construction shown in figure 1, as follows: Draw a line A H making any convenient angle with A I and lay off on it 7 equal convenient lengths, so as to bring H approximately opposite

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I. Join H and I, and with ruler and triangle draw the intermediate lines through B, C, D, etc., parallel to H I. These lines divide A I into 7 parts each=500 yards. The left division, called the extension, is similarly divided into 5 parts each equal to 100 yards.

Problem 2. R. F. $\frac{1}{10000}$, length of stride 60 inches. Construct a working scale of strides.

Solution: 1 STRIDE=60 INCHES. 1 inch=10000 INCHES=$\frac{10000}{60}$ STRIDES.

Suppose a 3 inch scale is desired. 3 inches=3×$\frac{10000}{60}$=500 STRIDES. Construct the scale by dividing up three inches into 5 parts of 100 STRIDES each by the method of figure 1.

Problem 3. A sketcher's horse trots one mile in 8 minutes. Construct a scale of minutes and quarters, R. F. $\frac{1}{21120}$. Solution:

8 MINUTES=63360 INCHES.

1 INCH=$\frac{(\ 8\ )}{(63360)}$ MINUTES.

From which 21120 INCHES=$\frac{(21120 \times \ 8\ )}{(\qquad\qquad 63360)}$

MINUTES=$\frac{8}{3}$=$2\frac{2}{3}$ MINUTES.

Since 1 inch=21120 INCHES,

1 inch=$2\frac{2}{3}$ MINUTES.

6 inches=(6×$2\frac{2}{3}$) MINUTES=16 MINUTES.

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Construct the scale by dividing the 6 inch line into 16 equal parts for MINUTES, and the left one of these spaces into 4 equal parts to read quarters of a minute.

R. F. NOT GIVEN.

Problem 4. An American officer in Germany secures a map showing a scale of 1 centimeter=1 KILOMETER.

Required (a) the R. F. of this map, (100 centimeters=1 meter; 1000 meters=1 kilometer.)

Solution: $\frac{1 \text{ cm}}{1 \text{ KM}} = \frac{.01 \text{ m}}{1000 \text{ M}} = \frac{1}{100000} = \text{R. F.}$

(b) How many inches to the MILE in this scale?

(c) Construct a reading scale of MILES for this map.

Problem 5. (Where a map has a graphical scale on which the divisions are not in even parts of inches and are marked in ground distances of some unfamiliar unit as kilometers, meters, chains, etc. It is required to construct a graphical scale in familiar units). By measurement on the scale of a German map, 1.08 inches reads 1 KM. (a) What is the R. F. of the map? (b) Construct a graphical scale to read YARDS. Solution 1.08 inches=1 K= 1000 METERS (1 m=39.37 in.). 1.08 inches= 39370 INCHES or 1 inch=36453 INCHES, or R. F.$= \frac{1}{36453}$; whence construct graphical scale as in Problem 1 (b).

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Problem 6. (Where a map has no scale at all. In this case measure the distance between two definite points on the ground represented, by pacing or otherwise, and scale off the corresponding map distance. From this find the R. F. and construct the graphical scale as above). For example, suppose the distance between two road crossings, identified on map and ground, is found to be 500 PACES (31 inches each), and on the map to be $\frac{3}{4}$ inch. In this case $\frac{3}{4}$ inch$=(500\times31)$ INCHES.

$$1 \text{ inch}=\frac{500\times31}{\frac{3}{4}}=20666.66 \text{ INCHES; R. F.}=\frac{1}{20666.66}$$

From this R. F. a scale of yards is constructed as in Problem 1 (b).

CHANGING THE SCALE OR THE AREA OF MAPS.

Note the difference between increasing or decreasing *the scale* (*linear dimensions*) of a map, and its *size* (*area*). To double the size of a map whose sides are six inches and 4 inches ($6\times4=24$ square inches), the reproduction would be 48 sq. inches that is $6\sqrt{2}$ by $4\sqrt{2}$ on the sides. To reduce a 9 inch by 6 inch map to $\frac{1}{3}$ its size (area), the sides would be $\frac{9}{\sqrt{3}}$ and $\frac{6}{\sqrt{3}}$. $\frac{9}{\sqrt{3}}\times\frac{6}{\sqrt{3}}=\frac{54}{3}=18=\frac{1}{3}$ of 54. The general rule is that to change the area of a map any multiple, as 2 times, 3 times, $\frac{1}{3}$ times, $\frac{1}{4}$ times, its original area, each of

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the linear dimensions is multiplied by the square root of the multiple as $\sqrt{2}$, $\sqrt{3}$, $\frac{1}{\sqrt{3}}$ $\frac{1}{\sqrt{4}}$, etc.

Problem 7. A map, R. F. $\frac{1}{6000}$, is enlarged so that the distance on the map between two towns A and B is 3 times as great as on the original. What is the new R. F.? Answer. R. F. $\frac{1}{2000}$, (R. F. multiplied by 3).

Problem 8. A map has R. F. $\frac{1}{8000}$. (a) What is the scale of this map in inches per MILE if its linear dimensions are decreased one-fifth in reproduction? (b) The original area of the map was 8 by 16 inches. What is the new R. F., if its area is four times as large as that of the original?

Solution to (b): $\frac{1}{8000} \times \sqrt{4} = \frac{1}{8000} \times 2 = \frac{1}{4000}$ = R. F.

CORRECTION OF ERRONEOUS SCALES.

It sometimes happens that in making a map an error exists in the length of the unit of measure that is not discovered until later. The question is then (1) how to find the true scale of the map as made, and (2) how to correct the working scale so it will be true for the future work.

Problem 9. An officer is ordered to make a position sketch, scale 6 inches=1 MILE. He uses a working scale of 62 inch strides. Afterwards he finds that his stride is actually 58 inches.

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Required: (a) What is the R. F. of the sketch actually made, and (b) is the scale larger or smaller than ordered?

Solution: (a) R. F. assumed $\frac{1}{10560}$. Since his stride was shorter than assumed, in plotting any given distance on the sketch (as 1 inch), he had actually passed over a shorter distance on the ground than he thought. Consequently his true R. F. would have a smaller *denominator* in the proportion of the true and assumed rates, 58 to 62.

$$10560 \times \frac{58}{62} = 9878.70 \text{ INCHES.}$$

The true R. F. of sketch was $\frac{1}{9878.70}$

(b) The R. F. $\frac{1}{9878.70}$ is larger than R. F. $\frac{1}{10560}$ having a smaller denominator, and therefore the scale of the sketch as made is too large.

Problem 10. A mounted sketch is made on the scale of 8 inches=1 MILE, with a horse rated at 5.5 MINUTES=1 MILE. The true rate of the horse is 1 MILE in 6 MINUTES.

Required: The true R. F. of the sketch.

Solution: Since the horse took longer to pass over a mile, than was thought, he traveled slower than he was rated. There was accordingly too short a distance covered at the end of any given number of minutes. Hence the distance on the ground corresponding to any plotted map space, say one

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inch, was less than supposed, or the denominator of the R. F. is really less than 21120, in the proportion of the two rates: $21120 \times \frac{5.5}{6} = 19360$. The true R. F. is $\frac{1}{19360}$.

Problem 11. A sketcher is ordered to make a sketch on the scale R. F. $\frac{1}{21120}$. He supposes he takes a 29 inch pace and uses this for his working scale. Afterwards he finds that a distance of 4000 yards scaled from his sketch measures on the ground 4125 yards.

Required (a) His true length of pace.

(b) The true R. F. of the sketch as made.

$\frac{4000 \times 36}{29} = 4965$=number of paces taken in traveling the distance, *whether he assumed the correct length of pace or not.* But in-as-much as the corresponding distance on the ground measured 4125 yards, therefore dividing this distance by the number of paces taken in passing over it, gives the true length of each pace: $\frac{4125 \times 36}{4965} = 29.9$ inches=actual length of pace.

(b) If the distance of 4000 yards scaled from the sketch actually measured 4125 yards on the ground, the sketch is smaller than intended and the R. F. $\frac{1}{21120}$ is too large and must be decreased in the proportion of these two distances, i. e. its

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denominator must be increased. (See par. 15). Therefore, $\frac{1}{21120} \times \frac{4000}{4125} = \frac{1}{21780}$ =true R. F.

THE LARGEST SCALE POSSIBLE ON A GIVEN SHEET.

Problem 12. A sheet of drawing paper 28 inches by 21 inches is to contain a map of an area of ground ten miles by seven miles and leave a border of at least $1\frac{1}{2}$ inches.

Required: The largest scale that can be used.

Solution: Taking out the border of $1\frac{1}{2}$ inches on every side leaves 25×18 inches available. The largest possible scale will be determined by finding the R. F. of a map that would require 25 inches to show 10 miles, and one that would require 18 inches to show 7 miles and using *the smaller of the two.* 25 inches=10MI.=63360 × 10=633600 INCHES.

1 inch $= \frac{633600}{25} = 25344$ INCHES. R. F. $\frac{1}{25344}$ is the scale of a map that will exactly fit the length.

18 inches=7 MI.=63360×7=443520 INCHES.

1 inch=24640 INCHES. R. F. $\frac{1}{24640}$ is the largest scale that can be used on the width.

The map that just will go on the 25 inch length will cover less than the 18 inch width and therefore

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R. F. $\frac{1}{25344}$ is the greatest scale that can be used. The map on any larger scale, as for instance $\frac{1}{24640}$, would not go on the length of 25 inches.

GENERAL SCALE PROBLEMS.

Problem 13. Construct a working scale of paces for a map on the scale of 12 inches=1 MILE, one hundred and twenty paces being equal 100 yards.

14. A reduction of the General Staff map of France is published on a scale of R. F. $\frac{1}{200000}$.

(a) Construct a graphical scale to show 15 miles on this map. 4.752 inches = 15 Mi.

(b) Construct a graphical scale to show 15 kilometers (1 meter=39.37 inches, 1 kilometer=1000 meters). 2.95 inches = 7.5 c. m. = 15 K. M.

15. The R. F. of a map size 10 x 12 inches is $\frac{1}{62500}$.

(a) What is the scale of this map when reduced to one-fourth its present size? $\frac{1}{125000}$

(b) Suppose that the length of the map becomes 9.5 inches in a photographic reproduction. Is the map enlarged or reduced? What is its R. F.?

16. What is the R. F. of the Leavenworth Map herewith? How many inches on it equal one mile?

17. A map was drawn on the scale R. F. $\frac{1}{10000}$ but in reproduction its dimensions were changed so

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that 800 yards on the ground scales 875 yards on the map.

Required: (a) Construct a reading scale to give correct distances from this map. (b) What is the correct R. F.? 1 ÷ 9143.

18. Draw a suitable scale of yards for a map 10 by 12 inches to show an area of 5 by 6 miles.

19. The R. F. of a map is 1÷10000.

Required: (a) the distance in miles shown by one inch on the map. (b) Construct a graphical scale of yards; also one to read miles (problem 1 b).

20. The map from which figure 16 was reduced has a graphical scale on which 1.56 inch=one kilometer. Required (a) the R. F. of the original map. (b) Number miles represented by one inch. (c) Graphical scale to read hundreds of yards; one to read miles.

21. A map has marked on it R. F. 1÷62500. Required: (a) graphical scale to read miles, halves and quarters. (b) What is the value in yards of one inch on the map? 1 inch = 1736.1 Yds.

22. You are in hostile country and secure a map of the locality without a scale. 20 inches on the map is the distance apart of the 20th and 21st degrees of latitude. Required: (a) a graphical scale of yards. (b) The R. F. of the map. (1° latitude=68.8 miles).

23. What is the R. F. of map, figure 20 A?

SCALING DISTANCES FROM A MAP.

20. Having considered the scale relation and the construction of scales, it is well to mention the use of scales in taking distances from a map.

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1st. Apply a piece of straight edged paper to the distance between two points to be measured and mark the distance on the paper. Now apply the paper to the graphical scale as shown in figure 2, and read the number of yards on the main scale adding the number on the extension, with a total of 600+75=675 yards.

2d. Take the distance A B, figure 2, off with a pair of dividers and applying the dividers, thus set, on the graphical scale read off 675 yards.

3d. Use an instrument called a map measurer,* figure 3. Setting the hand on its face to read zero, roll the small wheel from A to B. Now roll the wheel back to zero in an opposite direction along the graphical scale, noting the number of yards passed over on the scale. Or, having rolled from A to B, note the number of inches on the dial and multiply this by the number of miles per inch given on the map. *A map measurer is especially valuable for use in map problems and war games.*

4th. Apply scale of inches to the line and multiply the number of inches between the points by the number of miles per inch given on the map.

5th. Copy off the graphical scale on the edge of a piece of paper, and then apply this directly to the map.

If the line to be measured changes direction, the same methods are used.

By the 1st Method. Each portion in succession is taken off on the straight-edge paper.

*For sale by Keuffel & Esser Co., New York. Price $2.00.

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By the 2d Method: The dividers are first applied to B *a* (figure 4), then the leg at B is placed at B′ in the extension of *b a;* now the leg at *a* is placed at *b*, making *b* B′=*b a* + *a* B. Now rotate the leg from B′ to B″ in prolongation of *b c*. Move leg at *b* to *c*. The total distance is now included in the spread of the legs and the dividers are applied to the scale. By the *3d Method*: The map measurer is rolled from B to *a*, *a* to *b*, *b* to *c* (figure 4), causing the small wheel always to rotate in the same direction. *By the 4th Method*: The scale of inches is placed on B *a*, then rotated about *a* and placed along *b a*, thus adding B *a* to *a b*, etc., to the end, then obtain the number of miles as explained above.

PROBLEMS IN SCALING DISTANCES.

21. Problem 1. What is the distance from 70 (U. S. Pen.) to A via Prison Lane and Pope Avenue (Ft. Leavenworth Map)? Check by 3d method.

Problem 2. What is the distance from 70 to G over the Atchison Pike? Use the 4th method and check with the divider method.

Problem 3. A patrol at XVII (On Grant Avenue) is ordered to move by the shortest road to 17. Which road will it take?

Problem 4. Company A is at Grant and Metropolitan Avenues, Company B is at the Polo Grounds. They are ordered to arrive at Frenchman's at the same time. Assuming both move at 3 miles an hour, which will start first and how much? Give route of each.

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CHAPTER II.

METHODS OF REPRESENTING DIFFERENCES OF ELEVATION.

22. Since maps are representations, on a plane surface, of ground which has not only extent horizontally but vertically, it is necessary to have some means of rapidly determining elevations. This is accomplished in one of two ways.

1st. *By means of contours,* which are the lines cut from the surface of the earth by imaginary horizontal planes at equal vertical intervals from each other, figure 5 A.* The representations of these lines to scale on a map are called contours, figure 5 B, and this is the meaning usually intended by the term "contour." These relations of contours will be evident from figures 5 A and 5 B. Suppose that formerly this island was entirely submerged and that by a sudden disturbance the lake subsided until the highest peak of the island extended slightly above the water. Later a succession of falls of the water level of 20 feet each occurred, until now the island stands more than 100 feet out of the lake, and at each of the 20 foot elevations a distinct water line is left. These water lines are perfect contours referred to the lake as a reference (or *datum*) plane. It will be observed that on the gentle slope along

*Based on photograph of Crater Lake made by Geological Survey.

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F-H the 20 foot contour is far from the lake, and from the 40 foot contour. But on the steep slope at R the contours are very close together horizontally and almost directly over the water. Hence, it is seen that contours far apart horizontally indicate gentle slopes, and contours close together horizontally, steep slopes. It is also seen that the shape of the contours gives an accurate idea of the form of the island. Figure 5 B shows the *horizontal projection* of the contours in 5 A, that is, each point dropped vertically down on a plane. The contours in 5 B give an exact representation not only of the general form of the island, the two peaks, the stream M-N, the saddle M, the water shed from F to H, and the cliff at K, but the slopes of the ground at all points. From this we see that the nearer the contours on a map are to each other the steeper the slope represented. The contours of a cone (figure 6) are concentric circles, equally spaced because the slope of a cone is constant at all points. The contours of a concave cone are close together at the center (top), growing farther apart toward the outer circle (bottom), figure 8, showing that the slope is steeper at the top than at the bottom. The contours of a hemisphere are far apart at the center (top), growing closer together near the circumference (bottom), figure 7.

23. The following additional points should be remembered about contours:

(a) A *water shed or spur,* along which the water divides, flowing away from it on both sides, is

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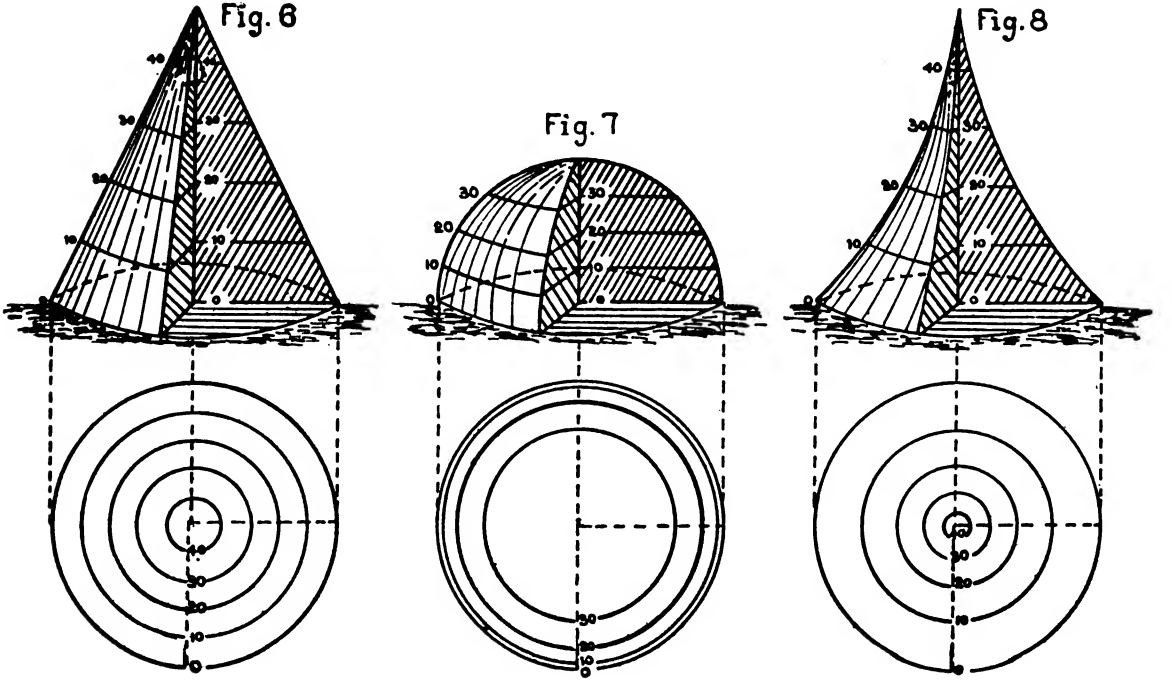
Plate 3



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indicated by the higher contours bulging out toward the lower ones. (F-H figures 5 A and 5 B).

(b) A *water course, or valley,* along which rain falling on both sides of it joins in one stream, is indicated by the lower contours bending out sharply toward the higher ones. (M-N figures 5 A and 5 B).

(c) Contours of different elevations which unite and become a single contour, represent *a vertical cliff*. The contours of the vertical faces of the quadrant cut out of the cone, figure 6, would be shown by two single lines, perpendicular to each other at the center of the concentric circles.

(d) Two contours of different elevations which cross each other represent an *overhanging cliff*.

(e) A closed contour represents either a *hill top* (crest), as P-B figure 5 B, or a *depression.* A hill top is shown when the smallest closed contour is higher than the adjacent contour, and a depression when the smallest closed contour is lower than the contour next to it.

(f) *A saddle (or col)* is shown by two contours of greater elevation on two sides of it, and two of lower elevation on the other two sides, as at M figure 5 B. M is a saddle between the two peaks 90 and 100.

24. Fig. 14 shows the stream system of the area represented in figure 15. Note the steep cliffs at A, figure 15, also observe that the roads generally fol-

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low the flat country. The road from Mt. Airy Lodge to Chilton makes a detour to avoid the steep slopes between these two places, but the road from Chilton to Stratford lies straight across the valley because its slopes are gentle, as shown by the greater distance apart of contours. A study of the network of streams in figure 14, in comparison with the contours in figure 15, will show the value of carefully noting the position and direction of flow of streams in map reading.

RELATION OF MAP DISTANCES, CONTOUR INTERVALS, SCALES AND SLOPES.

25. The horizontal distance on the ground between two contours is called the *Horizontal Equivalent* (H. E.) The horizontal distance between two contours on the map is always referred to by using the abbreviation *M. D.* (*map distance*). Since the M. D. depends on the slope of the ground represented, it can be calculated for various degrees of slope of the ground and a scale of M. D.'s constructed with which slopes can be at once read off from the distance apart of any particular contours. This is based on the fact that 57.3 feet (688 inches) horizontally on a 1 degree slope gives a rise of 1 foot. These relations are not absolutely correct, but up to 20° are so nearly exact that the error is not appreciable on the scales used on military maps.

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Slope degrees	Rise feet	Inches Horizontal
1°	1	688
2°	1	$\frac{688}{2}$ = 344
3°	1	$\frac{688}{3}$ = 229
4°	1	$\frac{688}{4}$ = 172
5°	1	$\frac{688}{5}$ = 138

26. To construct a scale of M. D.'s for a map on which it is not shown, take the distance in inches corresponding to one degree of slope, multiply this by the contour interval (V. I. in feet) and by the R. F. The result is the M. D. in inches for a 1° slope. Divide this value by 2, 3, 4 etc., then lay off these distances on a line to show 1°, 2°, 3°, etc., figure 10, p. 38. This relation between M. D., slope, V. I., and scale, is shown mathematically by the following formula: $M.\ D.\ (inches) = R.\ F. \times V.\ I.\ (ft.) \times 688\ (inches) \div (degrees)$. A discussion of the relations between the four terms of this formula gives rise to the principles governing slopes, map distances, scales, and vertical intervals of maps. These principles may be deduced by assuming that two of the quantities are fixed in value, and showing how the other two vary under those circumstances.

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27. The equation may be written thus: M. D. $\times$ S = R. F. $\times$ V. I. $\times$ 688. If now M. D. and S on two maps are assumed to be definite fixed values (as for example .65 inch M. D. and a corresponding slope of 1° on each map), their product is a constant. Hence the product of R. F. times V. I. must be constant to maintain the equality of both members of the equation and the R. F. must vary inversely with the V. I. for this condition to exist. That is, *If the R. F. (scale) is INCREASED the V. I. must be proportionally DECREASED and vice versa.* This principle is of great value in map reading and sketching because on all maps made on such a system a given M. D. represents the same slope.

The above principle may also be shown graphically as follows: Let figure (a) be assumed to be a vertical section of the ground in which the line A B is the horizontal distance and BC the V.I. between two contours A and C on the *ground.* If a certain M. D. on a map (No. 1) represents the distance AB on the ground, and the same M. D. on another map (No. 2) represents a *greater* ground distance, as AD, then the R. F. (scale) of map No. 2 is *smaller* than that of map No. 1 (see p. 4, last paragraph). But Map No. 2 has the larger V. I., as shown by the line ED in the figure; and hence the smaller the R. F. the larger the V. I. will be, if a given M. D. represents the same slope on all the maps.

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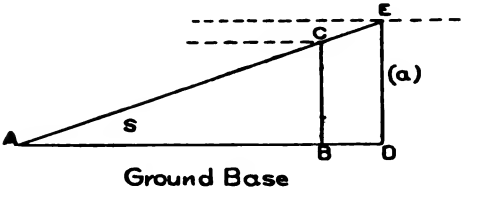

28. Based upon the above principle, *the Normal System of Scales* prescribed for U. S. Army field sketches is as follows: For road sketches, 3 inches = 1 *mile,* vertical interval between contours 20 feet. For position sketches 6 inches = 1 *mile,* V. I. = 10 feet. Fortification sketches, 12 inches = 1 *mile,* V. I. = 5 feet. On maps made according to this system, *any given length of M. D. always corresponds to the same slope.* Figure 10 gives this normal scale of M. D.'s for slopes up to 8°. A scale of M. D.'s is usually printed on the margin of maps, near the graphical scale. Having given the scale of the map to find what its V. I. would be on the normal system: *Divide the number of inches to 1 mile into 60,* and the quotient will be the required V. I in feet. The normal system is valuable both in sketching and map reading, because the map distances which represent slopes up to 8° or 10° are soon learned and no time is lost in determining the slopes represented on the map, or the M. D.'s corresponding to observed slopes on the ground.

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REPRESENTATION OF SLOPES.

29. Slopes are usually given in one of three ways: 1st in *degrees,* 2d in *percentages;* 3d, in *gradients.*

1st. A one degree slope means that the angle between the horizontal and the given line is 1 degree (1°).

2d. A slope is said to be 1, 2, 3, etc., percent, when 100 units horizontally correspond to a rise of 1, 2, 3, etc., of the same units vertically.

3d. A slope is said to be one on one (1÷1), two on three (2÷3), etc., when one horizontal unit corresponds to one vertical, three horizontal correspond to two vertical. The numerator usually refers to the vertical units. Degrees of slope are usually used in military matters; percentages are often used for roads, almost always for railroads; gradients are used for steep slopes, and usually for dimensions of trenches. Since 1° gives a rise of 1 foot at 60 feet (approximately), then 1° slope is equal to a gradient of 1 on 60 ($\frac{1}{60}$). 2° to 2 on 60= $\frac{1}{30}$. 3° to 3 on 60= $\frac{1}{20}$ etc. These values are useful for quickly giving an idea of the various degrees of slopes corresponding to gradients, and for converting one form of expression into another.

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Arm.	*Gait.*	*Distance.*		*Reduction for Slopes. In yards horizontally per ten feet vertically**	*Maxi'm Slope Practicable.*	
		Yards per Minute.	*Miles per hour*		*Deg.*	*Vert ÷ Hor.*
Infantry	March	88	3	Up: 10 Down: 10 for slope above 10°	45	1÷1
	Double	147	5	Down: 10 Up: 20 for slope above 10°	10 20	$\frac{1}{6}$ $\frac{1}{3}$
	Advancing by rushes	16				
	Advancing and firing	40				
Cavalry	Walk	117	4	Up: 40 for slope above 5° Down: 60 for slope above 5°	25 20	$\frac{1}{2}$ $\frac{1}{3}$
	Trot	234	8	Up: Same as walk Down: Same as walk	15 10	$\frac{1}{4}$ $\frac{1}{6}$
	Gallop	352	12	Up: Same as walk Down: Same as walk For slope above 3°	10 5	$\frac{1}{6}$ $\frac{1}{12}$
	Charge	440	15	Up: Same as walk For slope above 3° Down: Same as walk For slope above 2°	5 5	$\frac{1}{12}$ $\frac{1}{12}$
Artillery	Walk	117	4	Up: 10 Down: 60 For slope above 5°	10 10	$\frac{1}{6}$ $\frac{1}{6}$
	Trot	234	8	Up: 20 Down: 60 For slope above 3°	5 5	$\frac{1}{12}$ $\frac{1}{12}$
	Gallop	352	12	Up: 30 Down: 60 For slope above 2°	5 5	$\frac{1}{12}$ $\frac{1}{12}$

*Example. Artillery travels 60 min. on hilly road, going *up* hill a total of 100 ft. (vertically) and *down* hill a total of 50 ft. Required actual distance traveled: $117 \times 60 = 7020$ yds., distance if road had been level. $\frac{100}{10} \times 10 + \frac{10}{50} \times 60 = 400$ yds. $7020 - 400 = 6620$ yds. actually traveled.

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PROBLEMS.

31. 1. Construct a scale of M. D.'s for slopes from 1 to 8 degrees for a map whose V. I. is 20 feet, R. F. 1÷21120. Assume formula par. 26.

Solution: M. D.=(1÷21120)×20 ft×688 inches÷1°=.65 inch. Divide .65 inch by 1, 2, 3, giving M. D.'s for 1°, 2°, 3°. Lay these off as in figure 10.

2. Suppose you have a given slope between two contours, where the M. D. is 1 inch. How is the R. F. changed if, with the same V. I. and slope, the M. D. is 2 inches. Solution: V. I. and slope are constant, hence the M. D. varies directly with the R. F. The M. D. is doubled, hence the scale is doubled.

3. If on a given map a slope of 5° gives an M. D. of ½ inch, with a 10 foot V. I. what V. I. would give an M. D. of 1 inch to show the same slope. Solution: R. F. and S are constant, hence the V. I. varies directly as the M. D. which is doubled, hence the V. I. is 20 feet.

4. An M. D. of 2 inches, on a certain map represents a slope of 5°. How much must the scale of the map be altered for an M. D. of 5 inches to show 3° with the same V. I. as before? 2nd R. F. = 3/2 1st R. F.

These problems may be solved, by those familiar with the solution of equations, directly from the formula by substituting the quantities given directly in formula par. 26.

5. What is the steepest slope of the ground between "r" of the word Engineer and the bridge

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VIII east of Engineer Hill*? Ans.—6°, between the 830 and 850 contours. Solution: Take off on edge of a piece of paper the distances between the contours on line "*r*"—VIII. Applying these to the scale of M. D's, on the map it is found that 6° is the greatest angle of slope.

6. What is the percentage of grade along Grant Avenue from 800 contour (north of XVII) north to the 850 contour*? Ans. 5½%. Solution: Take off the distance between the 800 and 850 contours on a piece of paper, and, applying this to the graphical scale on the map, it is found to be 300 yards (900 feet). There are five contour intervals between the two points, or a rise of 50 feet. In 900 feet horizontally there is a rise of 50 feet; in 100 feet, a rise of 50÷9 feet=5.5+feet, or the grade is 5½%. (See definition of slope in percentage, par. 29.)

7. How would you express the above slope as a gradient?

8. Construct a scale of M. D.'s for the map in figure 15.

9. What is the steepest slope in degrees on the line A-B south of the Chilton-Mt. Airy Lodge road (figure 15)? What is the slope from B to the top of the first hill toward A (figure 15)?

10. Is the slope from the top of Sentinel Hill down to the main road at Gauss a convex, a concave, or a uniform slope? (see figures 6, 7 and 8)

11. Lay off a road from XXVI to the top of Long Ridge with a uniform 2° slope. Solution:

*Leavenworth Map.

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Take the 2° M. D. on edge of piece of paper from scale of M. D.'s. Place one end of the 2° distance at XXVI (830) and note where the other end touches the 840 contour. From this point proceed as before to 850 contour, etc. Join up the points marked on the successive contours by a line, which is the road with grade of 2°. Could more than one road with a 2° slope be laid off from XXVI to the hill top?

12. Given the following information, draw 20 foot contours to show the features named, on the scale horizontally of 3 inches = 1 mile: A hill is a mile long and rises 200 feet high from a plane; one side is a concave slope; another, convex; at one point there is a vertical cliff 50 feet high.

13. With the same scale and V. I., show a hill with two peaks connected by a saddle from which a stream runs down the hill.

14. Model on a sand-pile the hill shown on Plate 2 and mark on the model the contours as shown in the plate.

HACHURES.

32. A second method of representing, on a map, elevations on the ground, is by means of vertical lines called Hachures, figure 17. This method is not used in the United States, and most of the countries of Europe have abandoned it. Germany, however, still uses hachures for its small scale maps. Figure 17 shows a full size copy of the 1÷100000 map of Metz and vicinity accompanying Griepenkerl's Letters on Applied Tactics, and it should be understood by every military student. By compar-

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ing the Metz 1÷100000 map, figure 17, with the same area reduced from the 1÷25000 map, figure 16, on which contours are used, it will be seen that

Fig. 16

the contours give not only the exact elevations, but a much clearer idea of the slope of the ground than the hachures. Where no hachures are found on a hachured map, the ground is either a hill top or flat low land, and the slopes are roughly indicated by

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the varying blackness and nearness of the hachures. The darker the section the steeper is the slope. It often happens that a flat area is only known to be a

Fig. 17

hill top or valley by reference to surrounding features. Usually, however, figures indicate the heights of important points.

For reading maps of small scale a reading glass is of great assistance.

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CHAPTER III.

DIRECTIONS ON MAPS.

33. Having given the means used for determining horizontal distances and relative elevations represented on a map, the next step is the determination of horizontal directions. When these three facts are known of any point, its position is fully determined. The direction line from which other directions are measured is usually the true north and south line (known as the *true meridian*); or it is the line of the magnetic needle, called the *Magnetic Meridian*. These two lines do not usually coincide, because at all points of the earth's surface the true meridian is the straight line joining the observer's station and the north pole of the earth whereas the direction of the magnetic meridian varies at different points of the earth, at some places pointing east, and at others west, of the true pole. At the present time the angle which the magnetic needle makes with the true meridian (called *Magnetic Declination*) at Fort Leavenworth is 8° 23′ east of north. It is important to know this relation, because maps usually show the true meridian, and an observer is generally supplied with a magnetic compass. Figure 11 shows the usual type of Box Compass furnished to officers. It has marked on its face the four cardinal points, N, E, S and W., and a circle which should be grad-

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uated in degrees to read from zero clockwise around to 360, i. e. an observation to the east being read 90°.

METHODS OF ORIENTING A MAP.

34. In order that directions on the map and on the ground shall coincide, it is necessary for the map to be oriented, that is, the true meridian of the map must lie in the same direction as the true meridian through the observer's position on the ground. Every road, stream or other feature on the map will then be parallel to its true position on the ground, and all the objects shown on the map can be identified and picked out on the ground.

1st Method. When the map has a magnetic meridian marked on it, as on the Leavenworth map. Place the sighting line of the compass, *a b,* figure 12 (i. e. the north and south line of the compass face), on the magnetic meridian of the map and rotate the map horizontally, until the north end of the needle points towards the north of its circle, whereupon the map is oriented.

35. Where only the true meridian is on the map: Construct a magnetic meridian, figure 12, if the declination is known, as follows: Place the true meridian of the map directly under the magnetic needle of the compass, while it is pointing to zero, then, keeping the map fixed, rotate the north of the compass circle *in the direction of the declination of the needle* until the needle has passed over an angle equal to the declination. Draw a line on the map in the extension of the N-S line of the compass circle (a' b'), and this will be a magnetic meridian.

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Plate 4

Fig. 11

Fig. 12

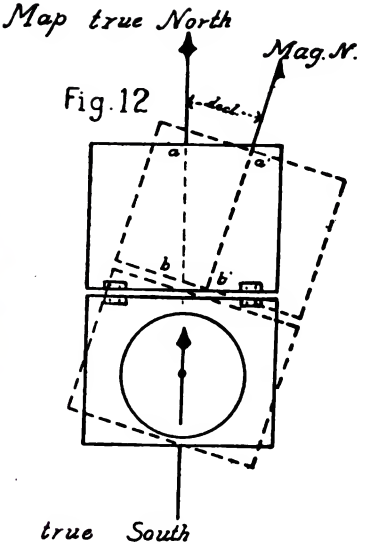


Fig 13

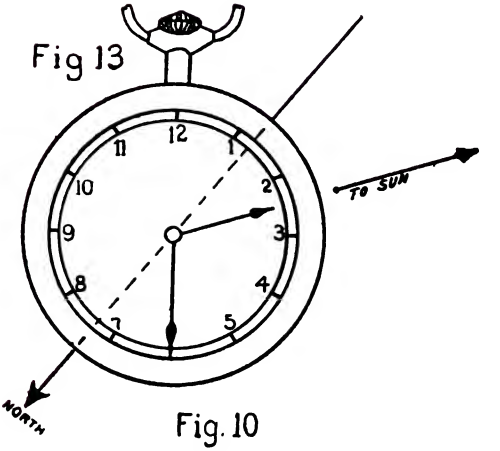
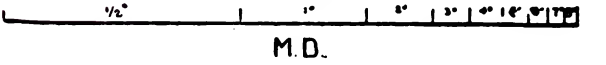


Fig. 10



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Having constructed the magnetic meridian on the map, orient it as under the 1st method.

If the magnetic declination at the locality is not more than 4 or 5 degrees, the orientation will be given closely enough for map reading purposes by taking the true and magnetic meridians to be identical.

2nd Method. When neither the magnetic nor the true meridian is on the map: (a) If you can locate on the map your position on the ground, and can identify another place on the map which you can see on the ground, join these two points on the map by a line and hold the map so that this line points toward the distant point seen on the ground, whereupon the map is oriented. (b) If you can place yourself *on the line* of any two points visible on the ground and plotted on the map, rotate the map until the line joining the two points on the map points toward the two points on the ground, whereupon the map is oriented.

TO LOCATE ONE'S POSITION ON A MAP.

36. (1) *When the map is oriented by compass* (a). Sight along a ruler at an object on the ground while keeping the ruler on the plotted position of this object on the map, and draw a line toward your body. Do the same with respect to a second point visible on the ground and plotted on the map. The intersection of these two points is your map position.

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(2) *When the map is oriented by the 2nd method* (b). Sight at some object not in the line used for orientation, keeping the ruler on the plotted position of this object and draw a line until it cuts the direction line used for orienting the map. This is your position on the map. Any straight line on the map such as fence, road, etc., is useful for orienting and thus finding your position. Usually your position may be found by characteristic landmarks, as cross roads, a crossing of railroad and highway, a juncture of streams, etc.

37. Having learned to orient a map and to find your position on it, you should secure a map of your vicinity and practice moving along roads at the same time keeping the map constantly oriented and noting exact features on the map as they are passed on the ground. This practice is of the greatest value in learning to read a map accurately; to estimate distances, directions and slopes correctly. The scale must be constantly kept in mind during this work, to assist in identifying your position at all times. Check off on the map the prominent points passed, such as bridges, cross roads, hill tops, villages, etc., and be sure that you identify correctly all objects of the terrain in your vicinity. You will find it difficult at first to constantly judge your position correctly, and from time to time will "lose yourself." When this occurs try to pick up your position again by careful observation of landmarks, assisted by an estimate of the map distance you should have traveled, at your present rate, from some point passed at a known hour.

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TRUE MERIDIAN.

38. The approximate position of the true meridian may be found as follows: Point the hour hand of a watch toward the sun; the line drawn from the pivot to the point midway between the outer end of the hour hand and XII on the dial will point toward the south, figure 13. To point the hour hand exactly at the sun, stick a pin, or hold up a finger, as shown, figure 13, and bring the hour hand into the shadow. At night a line drawn toward the north star from the observer's position is approximately a true meridian. The "pointers" of the big dipper are very nearly in line with the north star.

CONVENTIONAL SIGNS.

39. Having learned the means used to represent horizontal distances, elevations, and directions on a map, it is next in order to study the method of representing the military features of cover, obstacles, communications and supply. They include various kinds of growths, water areas, and the works of man. These features are represented by Conventional Signs, in which an effort is usually made to imitate the general appearance of the objects as seen from a high point directly overhead. On account of this similarity of the object to its representation, the student will usually have no trouble in deciding at once the meaning of a new symbol. There is a constant tendency toward simplicity in the character of conventional signs, and very often simply the outline of an object, such as forests, cultivated ground, etc., is indicated with the name of

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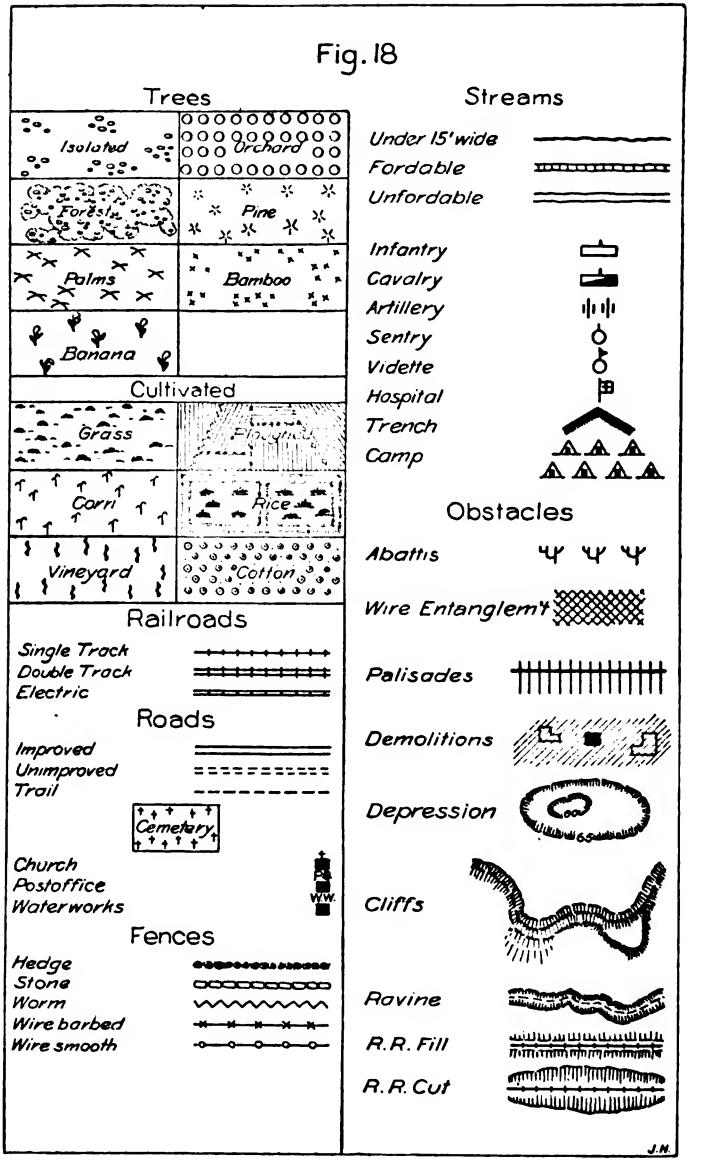

Fig. 18

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the growth printed within the outline. Such means are especially frequent in rapid sketches, on account of the saving of time thereby secured.

By referring to the map of Fort Leavenworth furnished herewith the meaning of most of its symbols are at once evident from the names printed thereon; for example, that of a city, woods, roads, streams, etc. Where no conventional sign is used on any area, it is to be understood that growths thereon are not high enough to furnish any cover. As an exercise, pick out from the map the following details: Unimproved road, cemetery, railroad track, hedge, wire fence, orchard, streams, lake. The numbers at the various road crossings have no equivalent on the ground, but are placed on the map to facilitate descriptions of routes or positions (as in the issue of orders). Often the numbers at road crossings on maps denote the elevations of those points.

40. Figure 18 shows the conventional signs prescribed by the War Department for surveys.

The conventional signs in figure 19 are those used in German maps and are generally very similar to those used in the United States. Every officer should be familiar with them to properly use the German War Game and Tactical Problem maps.

In the following table are the English equivalents for words and abbreviations found on German maps.

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WEGE—ROADS.

Saumpfad — Bridlepath (in mountains).
Fussweg—Path, Footpath.
Feld-und Waldweg—Field and forest road.
Gen. Verbindungsweg—General connecting road.
Gebesserter Weg—Improved road.
Gebauter Weg—Constructed road.
Chaussee—Highroad (macadam).
Daemme—Dams.

EISENBAHNEN—RAILROADS.

Eisenbahn—Railroad.
Strassenbahn—Street railroad.

GEWAESSER—STREAMS, Water.

Schilf—Reeds.
Bake—Beacon, buoy.
Tonne oder Boje—cask or barrel used for buoy.
Strauchbesen—broom corn.
Duene—sand dune.
Nasse Graeben—wet (damp) ditch.
Strom—Stream.
Bootshafen—Boat-landing
Eisenbahnbruecke — Railroad Bridge.
Kanal—Canal.
Schleusse—Canal lock.
Trockene Graeben—Dry ditch.
Muehle—Mill.
Wehr—Weir, Dam.
Steinerne Bruecke—Stone bridge.
Hoelzerne Bruecke—Wooden bridge.
Furt—Ford.
Fluss—Stream, creek, river.
Bach—creek.
Steg—Narrow foot bridge.
Bruecke mit Steinpfeilern—Bridge with stone piers.
Bruecke mit Holzpfeilern — Bridge with wooden piers.
Shiffbruecke—Pontoon bridge
Wagenfaehre —Wagon ford, (or ferry for vehicles).
Kahnfaehre—Ferry (for foot passengers).
Fliegende Faehre—Flying ferry.
Leuchtturm—Lighthouse.
Buhne—Pier (landing stage).

GELAENDEBEDECKUNGEN—FEATURES OF THE TERRAIN.

Laubholz—trees with leaves.
Nadelholz—trees with needles.
Gemischtes Holz—trees of both kinds (mixed woods).
Trockene Wiese—Dry Meadow.
Nasse Wiese—Wet Meadow.
Einzelne Baeume—Single trees.
Bruch, Sumpf—Swamp.
Waldboden—Woods.
Heide—Prairie.

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Stadt—City.
Flecken—Town.
Dorf—Village.
Gut—Manor, farm.
Vorwerk—detached farm.
Gehoeft—Farm.
Schloss und Parkanlage—Chateau and park.
Weinberg—Vineyard.
Baumschule—Nursery.
Hopfengarten—Hop Orchard.
Kirche, Kapelle, Kp.—Church, Chapel, Ch.
Forsthaus—Forester's lodge.
Windmuehle—Windmill.
Wassermuehle—Watermill.
Mauer—Wall (stone).
Knick—part wall, part fence.
Zaun—Fence.
Kirchhof—Churchyard, Cemetery.
Friedhof fuer Juden—Jewish Cemetery.
Ausgezeichn. Baum—Lone Tree.
Warte, Thurm—Town.
Bergwerksbetr—Mine.
Ruine—Ruin.
Denkmal—Memorial (statue or anything else).
Steinbruch, Stbr.—Quarry.
Grube—Pit, hole.
Felsen—Rock.
Alte Schanze—Old (abandoned) trench (rifle pit).
Trignometrischer Hoehenpunkt—Triangulation Station.
Reichs- und Landes Grenze—Kingdom and state frontier.
Regier.-Bezirk Grenze—Frontier of governmental districts.
Kreis-Grenze—District frontier.

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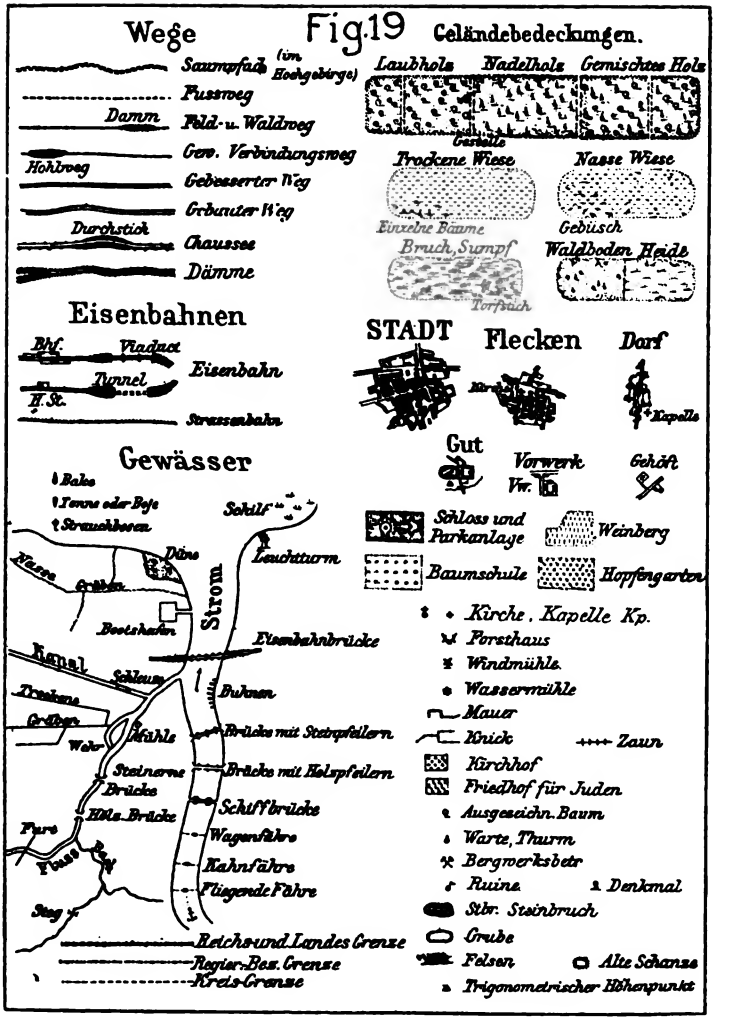

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CHAPTER IV.

VISIBILITY.

41. The problem of visibility is based on the relations of contours and map distances previously discussed, and includes such matters as the determination of whether one point can or cannot be seen from another; whether a certain line of march is concealed from the enemy; whether a particular area can be seen from a given point; whether slopes are convex, concave or uniform.

On account of the inherent inaccuracy of all maps it is impossible to determine exactly how much ground is visible from any given point over a given obstructing area; that is, if a correct interpretation of the map shows a given point to be just barely visible, then it would be unsafe to say positively that on the ground this point could be seen or could not be seen. It is, however, of great importance for the student to be able to determine whether such and such a point is visible or not, within about one contour interval; or whether a given road is generally visible to a certain scout, etc. In the solution of visibility problems, it is essential to thoroughly understand the meaning of profiles and their construction, consequently these matters will be explained here.

42. *A Profile is the line cut from the surface of the earth by an imaginary vertical plane.* The

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projection of this line to scale on a vertical plane is also called a profile. Figure 20 B shows a profile on the line D *a f*, figure 20 A, in which the horizontal scale is the same as that of the map, and the vertical scale is 1 inch = 40 feet. It is customary to draw a profile with a greater vertical than horizontal scale, in order that the slope of hills on the profile may appear more clearly to the eye for purposes of comparison. Always note especially the vertical scale in examining any profile; the horizontal scale is usually that of the map from which the profile is taken.

A profile is constructed as follows, Plate 8: Draw a line D′ *y′* equal in length to D *y* on the map.* Lay off on this line from D′ distances equal to the horizontal distances of the successive contours from D toward *y* on the map. At each of these contour points drop a perpendicular down to the elevation of this particular contour, as shown by the vertical scale on the left. For example, *a* is on the contour 870 and the perpendicular is dropped down to *a″* (870). Join successively the ends of these verticals by a smooth curve, which is the required profile of the ground on the line D *y*. *Profile or cross section paper* (lines ruled at right angles) simplifies the work of construction, but ordinary paper may be used.

43. Examining the profile, and drawing from

*The line D′*y′* may be assumed to have an elevation as great as the highest point, or as low as the lowest point in the profile, so that the profile will be *entirely below or entirely above* this line of reference.

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your eye at D lines tangent to the various hill tops, it is evident that looking along the line D *y*, you can see the ground as far as *a*; from *a* to *b* is hidden from view by the ridge at *a*; *b* to *c* is visible; *c* to *d* is hidden by the ridge at *c*.

1ST METHOD

By thus drawing a profile and lines of sight tangent to the various hill tops the visibility of any one point from another given point may be determined. The work may be much shortened by drawing the profile of only the observer's position (D); of the point of which the visibility is in question (Bridge XX); and of the probable obstructing points, (*a* and *c*). It is evidently unnecessary to construct the profile from D to *x*, because the concavity of the slope shows that there is no obstruction along this portion. The above method of determining visibility by means of a profile is valuable practice for learning slopes of ground, and the forms corresponding to different contour spacings.

44. Examining the profile we obtain the following important principles of visibility: (1) *Contours closely spaced on the top of a hill, gradually getting farther apart toward the bottom,* as D *x*, show a concave slope, and all points of the intervening surface are visible from top and bottom.

(2) *Contours spaced far apart at top, growing gradually closer together toward the bottom,* as *a n*, show a convex slope, and neither end of the slope is visible from the other.

(3) *Contours spaced equally distant apart,* as

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c f, indicate a plane surface, and all intervening points are visible from top to bottom of the slope.

The profile is the basis of all methods of determining visibility, but their construction is too slow for general use, except in acquiring skill in map reading. A simple and rapidly applied method is as follows:

45. *2nd Method.* Examine the line D *y* on the map, and by inspection determine the point or points which will be liable to obstruct the view to the desired point, the bridge *XX*. It can be seen at once from the three principles of contour spacing that the hills at *a* or *c* will be the only points to be considered. First determine whether *a* or *c* is the obstructing point. In order that *a* may be the obstructing point, *c* must lie below the line of sight from D tangent to *a*; that is, below *z*. It will be observed that for each distance D *a* (1.8 inches) the line of sight D′ *a*″ falls 90 feet (from contour 960 to contour 870). Applying a scale of inches (or folded piece of paper) from *a* toward *f*, figure 20 A, it is seen that one-half of 1.8=.9 inches horizontally gives a drop of $\frac{1}{2}\times 90$ feet=45 feet in the line of sight, *D′ a*″, which is here at an elevation of 825, and at *c* (on the map) it is still further below *c*″ (at *z*). Hence *c* is the obstructing point with respect to the bridge *XX*. In the same way, for the bridge *XX* to be visible over *c*, it must lie *above* the line of sight tangent to *c*. Applying the scale, D′ *c′* is found to be 3 inches long with a drop in the line of sight of 110 feet (*c*″, elevation 850). Now the point one-fourth of 3 inches=.75 inch, *forward*

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from c is at k slightly beyond XX, and the line of sight in this horizontal distance has dropped $\frac{1}{4}$ of 110=27.50 feet below c, or it is at the elevation 822.5 feet (at k''). The bridge XX is below the line of sight and therefore invisible.

46. The second method of determining visibility is a rapid approximation of that shown in the profile, and depends on the principle of similar triangles that *the drop of the line of sight at any point is proportional to the horizontal distance of that point from the apex of the triangle* (see triangles D′ c' c'' and D′ d' d'' figure 20 B). It will in general not be practicable to determine the visibility of points by this method closer than to say that the line of sight pierces the ground between two adjoining contours.

47. The explanation of this method is rather long on account of the necessity of referring constantly to the horizontal projection of the profile D y, and to the profile itself, D′ y''. The practical application, however, is rapid and simple. For example, you would solve the problem as follows: (1) Inspect the line D f and note that the only two probable obstructing points are a and c. (2) Lay the scale of equal parts on the line and find D a to be 1.8 inches and from the contours, note that the drop is 90 feet; apply $\frac{1}{2}$ of the 1.8 inches forward from a with a further drop of 45 feet and you see that the line of sight tangent to a pierces the ground before reaching c, and hence c is the obstructing point. (3) Applying the scale to

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D *c*, you find it 3 inches long with a drop of 110 feet; and forward $\frac{1}{4}$ of 3 inches,=.75 inch, from *c* with a further drop of 27.50 feet, carries the line of sight beyond *XX* to *k* and about 20 feet above *XX*. Hence *XX* is invisible.

THE OBSTRUCTING POINT.

48. The point to be considered is on the side of the obstructing hill *away from the observer looking down, and toward him in looking up toward an object* whose visibility is in question. For example see *a* and *a''* Plate 8. If the profile lies directly over the top of the hill, so that it cuts the highest closed contour, the elevation of the obstructing point will be that of this highest contour as *a''* (870). If, however, the profile crosses the obstructing hill on an inclined water shed, as A *d*, figure 22, then the view may be obstructed by ground on the water shed higher than the contour. The elevation of this point *a*, is approximately found by drawing a line up the water shed and finding by interpolation the elevation of the point where this line cuts the profile line *A d*.

49. *To determine the point at which a line of sight over an intervening hill pierces the ground*: use the 2nd method to find between which two contours the line will pierce, and, having found this, construct the profile (1) of the observing point, (2) of the obstructing point, (3) of the ground between these two contours; (4) project the piercing point on to the map. For example: To find the piercing point of the line of sight from A tangent to

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hill *c*, figure 21; find by 2nd method that it pierces between the 740 and 750 contours. Erect perpendiculars to the line Ac to locate A′ and *c*′; draw line of sight A′ *c*′. Similarly locate *d*′ (740) and *g*′ (750); join *d*′ and *g*′ by a straight line, this is the profile of the surface of the ground between *d* and *g*. The point *m*′ at which the line of sight intersects *d*′ *g*′ is the piercing point and is located on the map at *m* by erecting the perpendicular *m*′ *m* to the line *Am*. With cross section paper this method is very rapid, and easy, since the horizontal and vertical lines are already drawn.

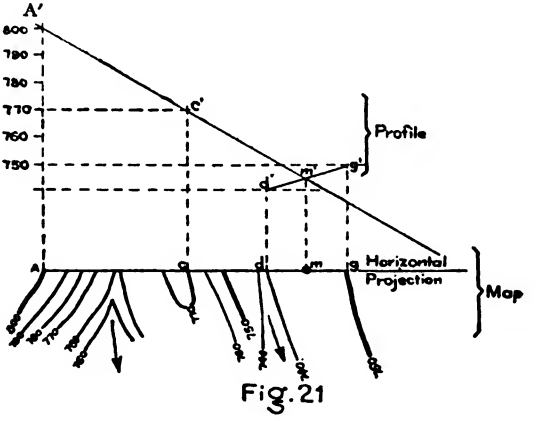

Fig. 21

SLIDE RULE FOR SOLVING VISIBILITY PROBLEMS.

50. As seen above, the solution of visibility problems requires the ability to solve proportions quickly and these proportions can be most rapidly solved with the Slide Rule. For a brief description of this valuable instrument and the methods of using it, see par. 220, Military Topography. It is well to

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solve a large number of visibility problems such as are given below, first by the profile method, and then by the Scale of Equal Parts method, then with the Slide Rule, until you become thoroughly familiar with the slopes represented by different spacings of contours. You will then be able to solve almost all essential visibility questions by a careful inspection of the map.

VISIBILITY OF AREAS.

51. The ground visible from any point of observation, will in general consist of a series of areas projecting above the crests visible to the observer, in the same way that the visible portions of the line D *y* were found to be D *a, bc* etc., above the visible crests *a, c,* etc. For example, to find the portion of the area represented on figure 20 A visible to an observer with his eye at D (960): First by inspection pick out all the points of the area evidently hidden by buildings, woods, high hills, etc., and those parts certainly visible. Then by passing profiles across the area from D, similar to D *y,* find the visible and invisible parts along these profiles. Join the obstructing points along each water shed by dotted lines to show the visible crests, or horizons, beyond each of which will be areas of invisibility. Similarly join the piercing points along each slope to mark the outer limits of the areas of invisibility.

VISIBILITY PROBLEMS.

52. Problem 1. From A (890) as observing point, find: (a) the visible horizon (crests dividing the seen from the unseen areas), (b) the invisible areas, and (c) those visible in the area figure 22.

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Answer: (a) the broken lines: C W; B E; N *d m a* F; Q H G; R I; K L; P *b c*. (b) C W Y; E B X; K L N *m a* F; Q H G; R I.

Solution: C W can practically be decided by inspection, but, to check this result, test the two profiles shown. The woods conceal the area between W and Y. Considering the woods south of railroad

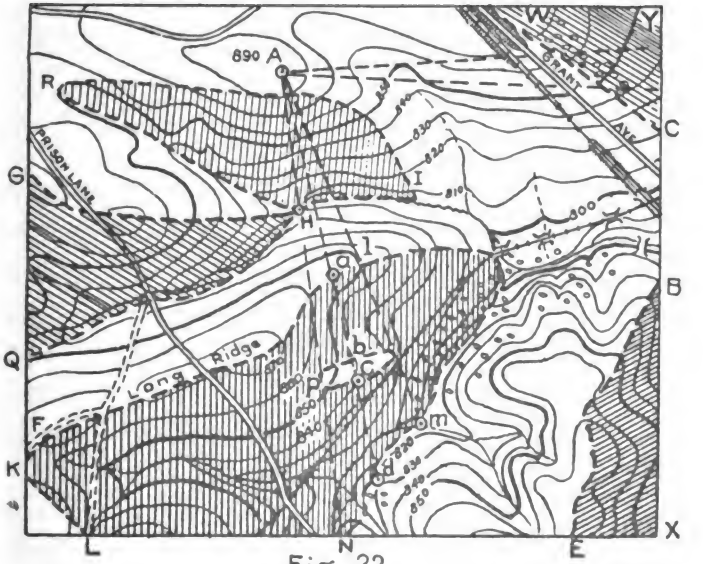

Fig. 22

as sufficiently thick to obscure the view, all of hill E would be hidden. Otherwise the crest of B E is found by inspection because of the steepness of the forward slopes toward X, as compared with the slopes of the lines of sight. The area R I is found approximately by inspection, and in the same way the visible crests along ridge F *a* and ridge H G are found. The most difficult position to solve is

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that south of Ridge F *a;* to determine this, draw lines tangent to the nose of each contour along the ridge as A *l m.* Find where these lines of sight pierce the ground and join these piercing points by a broken line as shown in the figure. It happens that there is a small area of visibility (*b* P *c*) on a second spur of the main ridge. This may be found by locating (method of par. 43 or par. 45) the piercing point on this auxiliary ridge, and then taking the far edge of this space as the obstructing line (*c* P) and finding over it the points of piercing, as at *d.*

With the slide rule the test on any such line as A *d* can be made in about one minute as follows:

Lay the scale of equal parts on A *d,* and leaving it there, read off values in inches below:

1st Test: At *a,* fig. 22, set 1.1 inch on Rule opposite 36 (feet drop) on the slide; read off opposite 1.53 inches (b) on Rule, 50 feet (840, piercing point) from Slide.

2nd Test: Set 1.65 inches (c) on Rule, opposite 50 feet (drop to 840 contour) on Slide. Read off opposite 2.18 inches (d) on Rule, 66 feet (824, piercing point) from Slide.

Problem 2. Is a patrol at 15 (elevation 855) visible to a scout at the letter C of the word Curran (elevation 980)? Answer, Yes. Solution: By inspection the probable obstructing point is seen to be the spur at M. Kern. Draw a line from 15 to C and take off on a piece of paper the distance from

Note: For problems 2, 3, 4, 5 and 6 see map of Fort Leavenworth.

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C to the obstructing point (contour 910). This distance gives a drop in the line of sight of 70 feet (980-910). Apply this distance once more beyond the obstructing point toward 15 and it shows the line of sight just south of 15 has an elevation of 840. The patrol is above the line of sight and is therefore visible.

Problem 8. Is the patrol at 15 visible to a scout on Curran House at elevation 1020? Answer, yes.

Solution: (*2nd Method, par* 46). Draw a line from 15 to Curran House (Leavenworth Map). The probable obstructing points are determined by inspection to be Bell Point or the Spur at Dishark. Take the distance, Curran House—Bell Point (930 contour) on a piece of paper. This horizontal distance gives a drop in the line of sight 1020—930= 90 feet. Fold the paper so as to divide the above distance into 8 equal parts each equal to 11¼ feet. Apply these parts from Bell Point toward 15. The fifth division falls on the Dishark Spur where the line of sight is at elevation 873.5, consequently the Spur does not interfere. Lay off the distance already taken on the paper (Curran House—Bell Point), along the line from Curran House twice toward 15. This brings the line of sight opposite the orchard at Sharp, with an elevation of 840. The patrol is above the line of sight, hence visible.

(Note—Check these two solutions by profile method. Problem 3 is more difficult, because it is not possible to determine by inspection which is the obstructing point.)

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Problem 4. How much of the road 15-E is visible from a point above McGuire House (elevation 1020)?

Method: Construct a profile of the obstructing crests and doubtful portions, see par. 49. Having constructed the profile, draw lines from the observer's position tangent to each ridge and note the hidden areas, as in figure 20 B.

(Note—Where a number of tests are to be made on one line, as in this problem, or where the exact point of piercing of a line of sight is desired, the profile method is preferable; otherwise the Slide Rule or Scale of Equal Parts methods are much more rapid).

Problem 5. Three Blue scouts are located as follows: On Schroeder's house (elevation 900); M. Kern's (elevation 920); Curran's (elevation 1050). A Red patrol is at Taylor School House (875). Can any one of the scouts see it? If so, which ones? (ignore trees).

Problem 6. Can a scout on northwest corner of the water works reservoir (870) see a battery on top of Sentinel Hill? (ignore trees).

Problems in visibility should be solved where possible on large scale maps at first.

ON USING MAPS IN THE FIELD.

53. Suppose you are in unknown country and are given a contoured map of a portion of the area your army now occupies, and are informed that later you are to make a reconnaissance based on this map. Learn the map as follows:

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(1) Observe the scale, see if it is in familiar units and how many inches equal 1 mile, so that you can make rapid mental estimates of the distance between prominent points shown. For purposes of estimation the end joint of the first finger is approximately one inch long. For example, the map, plate 5, is on a scale of approximately one inch to 1 mile. You see, therefore, that Stratford is about two inches, that is about 2 miles, from Chilton. Get this scale relation firmly fixed in mind for the map under consideration.

(2) Learn the contour interval, from the numbering on the contours, or by observing the number of contour intervals between two known elevations, usually marked on hill tops or cross roads. This will give you a clear idea of the relative heights of hills and depressions of streams; and will tell you which are commanding positions, good view points, etc.

(3) Observe the position of the true and magnetic meridians, and the number of degrees declination.

(4) Pick out the streams on the ground and map and trace them by eye throughout their visible length. This is a most necessary step in acquiring a good general knowledge of the ground and map, because the streams form the framework of the area upon which the contours are based. For instance, on the map figure 15, if the streams are first traced as shown, figure 14, it will be possible to imagine the approximate location of the hill tops and ridges and a skilled sketcher would be able with

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this data alone to draw a fairly good map of the area showing the ground forms.

(5) Next pick out the tops of all hills and trace the highest lines of all the ridges. You will be surprised to see how quickly the features of ground represented on the map begin to stand out clear and distinct. You will be assisted in picking out stream lines and watersheds on a properly made map, by noting that the contours heading on the stream lines are very pointed, whereas on watersheds the contours bulge out toward the bottom of hills in rounded curves. This is well shown in figure 15.

(6) Next construct (if not given) a scale of M. D's. for the map and learn the general character of slopes of the ground. See where the flattest and steepest parts occur and the approximately greatest angle of slope, also where troops can maneuver (see table of movements, par. 30).

(7) Pick out all towns and villages, noting their names, sizes, etc.

(8) Trace all roads and railroads and get a good idea which are main roads and which only field tracks.

(9) Next take up the particular points to be investigated and study the map with these in view. For instance, where are good defensive positions, camp sites, lines of observation, good roads with easy grades for the passage of trains, etc.

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MAPS USED FOR WAR GAMES AND TACTICAL PROBLEMS.

54. Two of the most important uses of maps by military students are in connection with the solution of tactical map problems and war games. It is customary to solve these problems with commands at war strength, and therefore it is important to have a clear idea of the spaces on the map occupied by bodies of troops of the different arms and the distances passed over at the normal foot and mounted rates of travel. Figure 23 gives this information for maps on the scale of 12 inches to 1 mile, which are normally used for war games. For tactical problems on maps of smaller scales, take one-twelfth, one-fourth, etc., of these spaces for the same values according as the map used is 1 inch to 1 mile, 3 inches to 1 mile, etc. You should familiarize yourself with these movements and spaces before beginning the solution of problems in tactics, in order to have a clear idea of the lengths of columns and distances of travel on the map.

The Secretary Army Service Schools has for sale at small cost the following maps: Antietam, Gettysburg, Ft. Leavenworth, 12 inches to 1 mile; Benjamin Harrison, 8.08 inches to 1 mile; Pine Plains, Mt. Gretna, Leon Springs, Ft. Leavenworth, 4 inches to 1 mile; Atascadero, 3¼ inches to 1 mile; Gettysburg, American Lake, Crow Creek (Wyoming), Fort Benjamin Harrison, 3 inches to 1 mile; Ft. Leavenworth, 2 inches to 1 mile.

The maps which are most generally available for military students in our country are those of the U.

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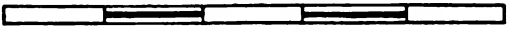
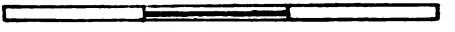
Scales of Movements

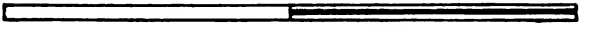
Inf. or mixed Troops 80 yds per min



Cav. and F. A. – Walk – 110 yds per min

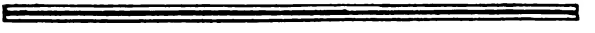


Cav and F. A. – Trot – 220 yds per min.



Cav. and F. A. Walk and Trot 147 yds. per min

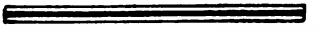
Mnt Messenger Gallop 440 yds. per min.



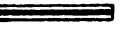
Road Spaces

Company 40 yds

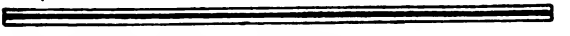
Battalion with Combat train – 210 yds.



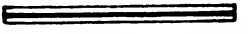
Troop – 90 yds.



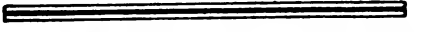
Squadron with Combat train – 420 yds.



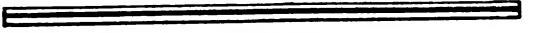
Light Btry (firing) 190 yds.



Light Btry. and Combat train – 320 yds.



Btry. complete, field train without dist. 380 yds



All units at war strength.

Fig. 23

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S. Geological Survey. These maps are made on three scales, as follows: (1) R. F. 1÷62500, or about 1″=1 mile, of the more thickly settled portions of the country; (2) R. F. 1÷125000, or about 1″=2 miles, of the moderately settled areas; (3) R. F. 1÷250000, or about 1″=4 miles, of the desert areas. The contour interval varies according to the relief of the ground. On each sheet are placed graphical scales of inches to miles, and centimeters to kilometers; the contour interval; a true meridian; a magnetic meridian; the mean declination at the date the map was made; and the latitude and longitude of the boundaries of the sheet. Each is named from the principal town covered by the sheets. On these maps water features are shown in *blue,* contours in *brown,* works of man and lettering in *black.* Although these maps lack certain details of importance to military students, yet they are of great value in solving military problems.

The Director, U. S. Geological Survey, Washington, D. C., will furnish, on request, a set of indexes of maps of the United States issued by his department. A single map costs five cents. Every officer ought to have the map of the section where his company is stationed, as well as the maps wherein are located the maneuver camps that his organization visits, and the four sheets around Gettysburg of which the 12 inch and 3 inch maps are for sale at the Service Schools.

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PART II.

MILITARY TOPOGRAPHICAL SURVEYING.

CHAPTER 1.

Military Topographical Surveying consists of the determination of all features of military importance in the area to be mapped, and their representation on a plane surface. It involves the location of unknown points on the surface of the earth by measurement of their angles of direction and distances from points whose horizontal and vertical positions are known. This is accomplished by the use of *Scales* on distance and angle measuring instruments. In order to make these required measurements, the means of comparing angles and distances are necessary.

SCALES AND VERNIERS ON INSTRUMENTS FOR MEASURING DISTANCES ELEVATIONS AND DIRECTIONS.

56. Every measurement in surveying is made by comparing distances, directions, or elevations, with certain similar units whose values are known. These known units laid off successively are called *scales*. For example, the foot, yard etc., are units of distance, and a tape marked at every foot is a scale of feet. The degree ($\frac{1}{360}$ of a circle) is

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the unit of angular measure, and a circle divided into 360 equal parts is a scale of degrees. The main part of the scale is called the *Limb;* the *Vernier* and limb together are called the scale, figure 31.

To read a scale, the zero of the limb is placed opposite the known point of the two being considered and the reading is taken along the scale to the required point called the *"index,"* usually marked by the zero (b) of the vernier on an instrument, or a stake if on the ground.

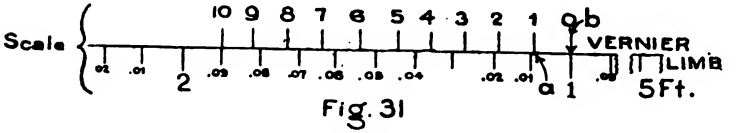

Fig. 31

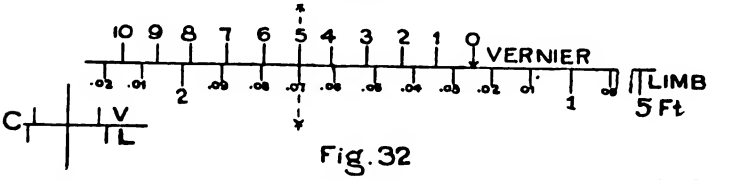

Fig. 32

57. *A vernier,* figure 31, *is an auxiliary scale for measuring smaller values than are given by the smallest divisions of the limb.* This fractional reading is obtained by making each least space of the vernier less or greater than one or more least spaces of the limb by *the amount of this least reading of the vernier.* In the vernier, figure 31, ten vernier spaces=nine limb spaces, and one vernier space= 9/10 of one limb space. Hence the small distance *"a"* equals 1/10 of a least scale space (.01 foot)= .001 foot=the least reading of the vernier (*L. R. V.*). Therefore if the vernier should be moved to

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the left until the 1 on the vernier coincides with .01 on the limb, the reading on the limb would be 5.1 and on the vernier .001, giving a total reading on the scale of 5.101 feet. Similarly if the vernier were moved forward to the left until the 2nd line of the vernier coincides with a division line on the limb, the index would now be .002 from 5.1 on the limb, and the total reading of the scale 5.102. The reading of the limb in figure 32 is 5.12 and of the vernier .005; total reading of the scale is 5.125 feet. This type of vernier, in which each least space of the vernier is *less* than the corresponding space (or spaces) on the scale is called a *Direct Vernier,* because the vernier must be read in the *same direction* as the limb. This vernier is the same as that on the N. Y. Level Rod, Figure 75. In figures 31 and 32, the limb is read from right to left beginning at zero of the limb up to the last division line of the limb before passing the index; and the vernier likewise from right to left, beginning at the *zero of the vernier* up to the vernier division line coinciding with a limb division line.

In figure 33 (a), ten least spaces of the vernier equal eleven spaces of the limb, one of the vernier $= \frac{11}{10}$ of one least space of the limb $= \frac{10}{10} + \frac{1}{10}$ or each vernier space is $\frac{1}{10}$ greater than one limb space (.01 feet) = .001 foot. If the index is moved to the left .001, the first division line of the vernier coincides with a division line of the limb; if it is moved .002, the 2nd division line coincides with

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another and so on. The reading on the limb, figure 33 (b), is 4.51 and on the vernier, .007; total reading 4.517 feet. In this case *the limb is read to the left and the vernier to the right* or in an opposite direction, and it is a *Retrograde Vernier.*

58. An examination of the two above sets of verniers gives the following *rules for constructing, for determining whether direct or retrograde, and for reading verniers*:

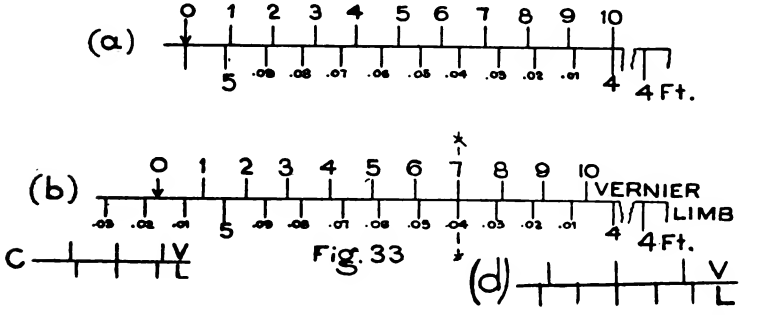

Fig. 33

(1) *The least reading of the vernier* (*L. R. V.*)=the value of a smallest space on the Limb (*L. R. L.*), divided by the number of the smallest spaces *actually shown on the vernier* (n); that is, L. R. V.$=\frac{\text{L. R. L.}^*}{\text{n}}$.

(2) *The two spaces of a direct vernier on each side of coincidence,* figure 32 (c), *lie entirely inside the corresponding spaces of the limb,* and of a *retrograde vernier,* figure 33 (c), *extend beyond the two corresponding spaces of the limb.* (By a *corresponding* † space of the limb is meant one, two, or

*For a double vernier n = one-half the total number of spaces shown on vernier.

†See fig. 33d, which is part of a direct vernier with every alternate division line omitted.

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more of the smallest spaces of the limb which most nearly equal *one smallest space of the vernier*).

(3) *The total number of smallest spaces (n) of a direct vernier cover n—1 corresponding spaces of the limb; the (n) spaces of a retrograde vernier cover n+1 corresponding spaces of the limb.*

(4) *To read a scale with direct vernier*: Read from the zero of the limb up to the division line im-

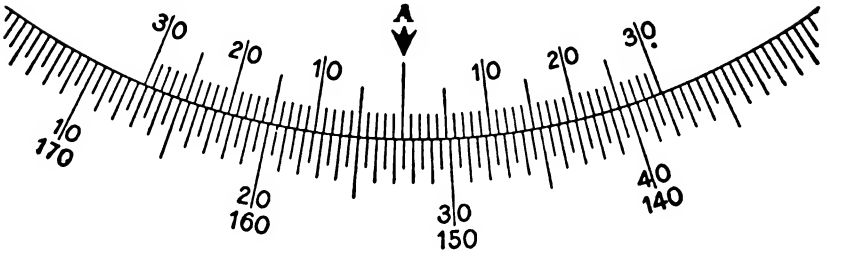

Fig. 34

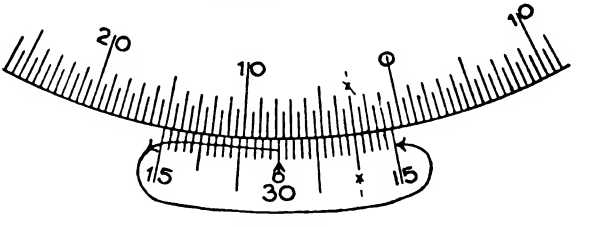

Fig. 35

mediately preceding the index of the vernier, then read in the *same direction* on the vernier from its zero up to the coincidence. The same rule applies where the vernier is retrograde, except that the vernier is read in an *opposite direction* from that in which the limb is read.

59. Figure 34 shows the direct vernier of the horizontal plate of a transit, of which the least read-

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ing of the limb is one-half degree and of the vernier is one minute. 30 spaces of the vernier cover 29 spaces of the limb, and the vernier is direct. This is called a *Double Vernier,* because it has two coincidences and gives two sets of readings, one corresponding to the outer graduation on the left half and the other to the inner graduation on the right half of the vernier. The scale reads 27°—00′+ 25′=27° 25′ from left to right, and 152° 30′+05= 152°35′ from right to left.

60. Figure 35, is the scale on the vertical arc of a transit, reading to single minutes. On account of the small space available for the vernier beside the transit standard, a *Folded Vernier* is used. This requires only half as much space as a double vernier giving the same reading. It is read in either direction depending on its position, from the index (arrow head) to 15, and then from 15 on the opposite end, forward in the same direction to 30. The reading in the figure is 7° 50′ from right to left. (see arrow) A *folded vernier has but one coincidence; a double vernier has two.*

All the scales upon engineering instruments with few exceptions have direct verniers. Barometers have indirect verniers.

PROBLEMS.

61. 1. The least reading of the limb of an angle measuring instrument is 1 minute. Its vernier has 6 spaces covering 5 spaces of the limb.

(a) Is this a direct or retrograde vernier?

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(b) What is the least reading of the vernier?

(a) Direct. (See rule 8, par. 58.)

(b) $\frac{\text{L. R. L.}}{n}=\frac{60'}{6}=10''$. The least reading of the vernier is 10 seconds.

2. Construct a vernier to read one hundredths on a limb whose least reading is one twentieth of a foot.

Solution: $\frac{\text{L. R. L.}}{n}=\frac{\frac{1}{20}}{n}=\frac{1}{20n}=\text{L. R. V.}=\frac{1}{100}$. Hence $\frac{1}{20n}=\frac{1}{100}$ and $n=5$. For a direct vernier 4 spaces on the limb are to be equalled by 5 spaces on the vernier; for a retrograde, 6 spaces of the limb are covered by 5 of the vernier. To divide the line of given length into 5 or 6 equal parts, follow method of par. 19, problem (b).

In case *each alternate or each third etc. division line of the vernier is omitted,* so that one space on the vernier corresponds to two, three or more smallest spaces on the limb the effect is to increase the L. R. V. twice, three times etc., and rules (1), (2), and (4) above still remain true. For instance, figure 31, if each alternate vernier division line were removed the least reading would be twice its present least reading (that is .002), as seen from figure 33d and from the formula $\frac{\text{L. R. L.}}{n}=\text{L. R. V.}$ In other words instead of the small space *"a"*, there would be a small space *"2a"* at the new 1st division line of the vernier to the left of the index, and n spaces of the vernier equal $2n-1$ spaces of the limb.

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3. Ten smallest spaces on a vernier cover 19 spaces of the limb. The least reading of the limb is 1 foot. What is the L. R. V., and is the vernier direct or retrograde? Solution: $\frac{L\ R\ L}{n} = L\ R\ V$ $= \frac{1 \text{ foot}}{10} = .1$ foot. It is a direct vernier because one space on the vernier is smaller than the corresponding spaces *(two)* of the limb.

4. Construct a double retrograde vernier to read 5 seconds on a limb whose least reading is 1 minute.

5. Construct a folded vernier to read 30 seconds on a limb reading to single degrees. See figure 35.

ANGULAR MEASUREMENTS.

1. HORIZONTAL ANGLES.

62. In all measurements a known point is necessary, with the position of which the locations of other objects are compared. This necessity has led to the use from the earliest times, of the position of the magnetic needle as the reference (or starting) line of all horizontal angular measurements, because it is the only object known to man which maintains its position with respect to horizontal angular motion. The *Magnetic Needle* points to the magnetic pole of the earth. The vertical plane in which lies the magnetic needle is called the *Magnetic Meridian.* The vertical plane containing the true north and south line at any point on the earth is called the *True Meridian.* The angle, measured at the north point, which the magnetic meridian makes with the true meridian at any place on the

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earth is the *Magnetic Declination.* Although the magnetic needle is more nearly fixed in position with respect to angles in the horizontal plane than any other object; yet at any point on the earth it varies from year to year in what is known as secular variation, so called because the change continues through a series or cycle of years. The declination also varies through an arc of about 8 minutes from day to day in what is known as diurnal (daily) variation. At 10:30 a. m. the needle has its true variation for the day. The declination of the needle is often increased or diminished by the presence of iron, steel, electric currents etc. The variation of the direction of the needle from these causes is said to be due to *"Local Attraction."*

There is an imaginary line on the earth's surface, joining all points at which the magnetic declination is zero. This line is called the *Agonic Line,* that is the needle at any point in this line is without magnetic declination. At points on the earth to the east of the Agonic Line the magnetic declination is west and at points west of the agonic line the magnetic declination is east. The agonic line in the United States at the present time extends from South Carolina through Michigan.

Since the true meridian at any point on the earth is definitely fixed and is forever unchanged in position, it is desirable to have measurements made from it instead of from the constantly varying magnetic meridian. In order to accomplish this result the magnetic declination should be known at the place

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and time of the survey. This is found by locating on the ground the position of the true meridian and the angle made with this line by the magnetic needle is the magnetic declination.

TO LOCATE THE TRUE AND MAGNETIC MERIDIANS.

63. *1st Method;* from the sun.—Prick a small hole in a piece of tin or opaque paper and fix over the south edge of a table or other perfectly level surface, so that the sunlight coming through the hole

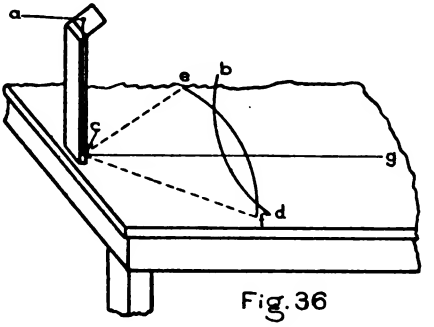

Fig. 36

will fall on a convenient place on the surface, figure 36. The hole may be two feet above the table for long days and 18 in. for short ones. Half an hour before, to half an hour after noon, mark the position of the spot of sunlight on the horizontal surface at equal time intervals of about 10 min. Draw a curve as *bd,* figure 36, through the points marked, and from a point *c* in the horizontal surface and in a vertical line with the hole *a* sweep an arc *ef* intersecting *bd* in two points. The line *cg* drawn from *c* through a point on the arc midway between the intersections, is the true meridian. The

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line *bd* illustrates the method merely. Its form varies with the sun's declination. (Engineer Field Manual.)

64. *2nd Method;* Observe the magnetic azimuth, see par. 69 of the sun (or a bright star) at rising and setting on the same day, or one night and the following morning. Subtract the eastern azimuth from the western (both measured from the north around through the east). Adding ½ of this difference to the eastern azimuth gives the magnetic

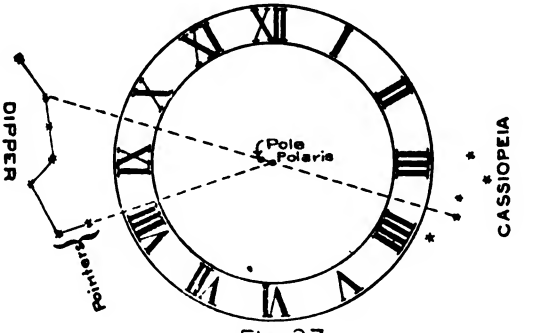

Fig. 37

azimuth of the true south point, figure 38. The two observations should be taken at the same gradient and both at zero gradient if possible. See figure 38, angle $\frac{(b-a)}{2}$ =angle $\frac{ysx}{2}$ =*yos*. Angle $\frac{(yox)}{(2)}$ +*a*=magnetic azimuth of the true south. Having found the magnetic azimuth of the true south, the difference between this and 180° is the magnetic declination. This method will give the true meridian within 15′.

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3rd Method; from Polaris.—The true north pole is about 1° 12′ distant from Polaris on a line joining that star with one (Zeta) in the handle of the dipper, and another (Delta) in Cassiopeia's Chair, figure 37. One of these stars can be seen whenever Polaris is visible. The polar distance of Polaris is decreasing at the rate of 19″ a year. It also varies during the year by as much as 1′. The latter variation may be neglected and the former for a series

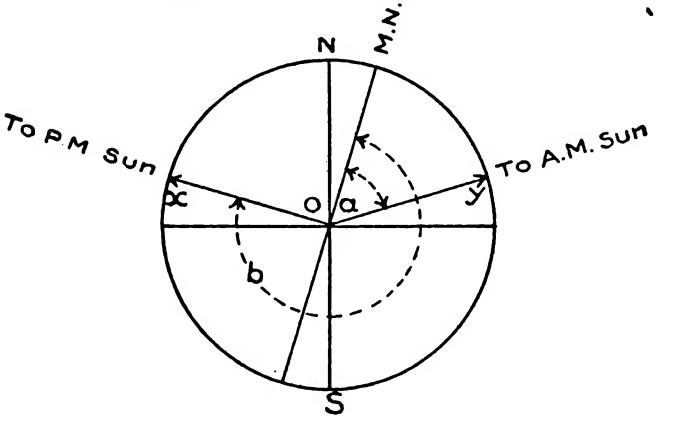

Fig. 38

of years. Imagine Polaris to be the center of the clock dial, of which the line joining 12 and 6 o'clock is vertical. Let the position of the line from Polaris to either of the two stars mentioned be considered as the hour hand of the clock. The distance in azimuth of Polaris (see par. 69) from the true north may be taken from the following table:

65. *Table showing the azimuths of Polaris* in different positions with respect to the pole. Epoch 1911; polar distance 70′. Latitude 0° to 18° north. This table may be used until 1930.

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Clock reading of—		Azimuth of Polaris	Clock reading of—		Azimuth of Polaris	Clock reading of—		Azimuth of Polaris
Δ Cass.	Z Ursae Maj.		Δ Cass.	Z Ursae Maj.		Δ Cass.	Z Ursae Maj.	
		′			° ′			° ′
XII:30	VI:30	18	IIII:30	X:30	49	VIII	II	358 59
I	VII	35	V	XI	35	IX	III	358 50
I:30	VII:30	49	V:30	XI:30	18	X	IIII	358 59
II	VIII	61	VI:30	XII:30	359 42	X:30	IIII:30	359 11
III	IX	70	VII	I	359 25	XI	V	359 25
IIII	X	61	VII:30	I:30	359 11	XI:30	V:30	359 42

For higher latitudes add to the small azimuths or subtract from the large ones, as follows:

Lat. 19°—30°, 1/10 Lat. 51°—53°, 6/10
Lat. 31°—37°, 2/10 Lat. 56°—57°, 7/10
Lat. 38°—42°, 3/10 Lat. 58°—59°, 8/10
Lat. 43°—46°, 4/10 Lat. 60°—61°, 9/10
Lat. 47°—50°, 5/10 of the true bearing of Polaris.

It is well to keep track of the position of Polaris by noting it frequently and taking the corresponding clock time. Then if on a cloudy night a glimpse of Polaris is had, the observation may be taken even though the other stars cannot be seen.

66. For *practical details of the observations,* the following may serve as a guide: Select a clear space of level ground not too near buildings or any object which might cause local disturbance of the needle. Drive a picket, leaving its top smooth and level, about 18 ins. above the ground. Six feet north of the picket suspend a plumb line from a point high enough so that Polaris, seen from the top of the picket, will be near the top of the line, figure 39. The line should be hard and smooth, and about 1/10 inch diameter. The weight at the bottom of the line should hang in a vessel of water or in a hole

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dug in the ground to lessen its vibration. Drive a second picket in range with the first one and the plumb line, a short distance north of the latter. Make a peep sight by punching a hole about 1/10 inch diameter in a piece of paper and hold it on the top of the first picket; adjust it so that the star is behind the plumb line when looking through the peep. Note the position of one of the stars on the imaginary clock face at the moment the observation

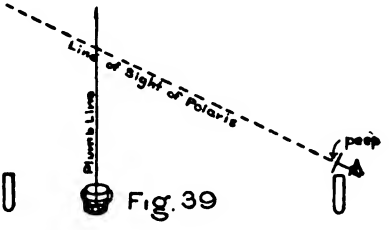

Fig. 39

is taken. Mark the position of the peep on the top of the first picket, and lay a straight edge or stretch a line from that point touching the plumb line to the second picket. Place the north—south edge of the compass box against the line or straight edge, and read the magnetic azimuth. Find the true azimuth of the star at the time of the observation from Table par. 65.

*Rules:** (1) If the true Azimuth of Polaris (Table par. 65) and the reading of the needle *are both less or greater than 180°*, their difference is the declination; *east if the needle reading is less, west if it is greater.* (2) If one of these quantities is less and *the other greater than 180°*, add 360° to the

*A figure similar to figure 40 will show the relative positions of the magnetic meridian, Polaris and the true meridian without the use of Rules.

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lesser and take the difference which is the declination; *east if after the addition is made the needle reading is less, west if it is greater than the tabulated azimuth.* This method will give results true to within ¼°. (Engineer Field Manual). Having found the Declination by one of the methods shown above, it may be set off on the transit or plane table compass, so that all the readings of the needle would be from the true meridian. (see par. 74).

PROBLEMS IN FINDING THE DECLINATION BY THE THIRD METHOD.

67. *Example 1.* Clock reading of ∆ Cassiopeia, V-30, azimuth of Polaris, (from table par. 65) 18′, magnetic azimuth 355 deg.

18′+360°=360°18′. 360° 18′—355°= 5° 18′. Compass reading is less than 360 degrees, hence the declination is 5°18′ east. (Rule 2).

2. Clock reading of Zeta Ursa Major is II, Azimuth of Polaris, 358° 59′, magnetic azimuth is 3 degrees.

360°+3°—(358°59′)=4° 1′ Declination west, because the needle reading plus 360° is greater than the azimuth of Polaris.

3. Suppose you have located the true meridian on the ground, and reading its magnetic azimuth with your compass, find it to be 347°20′.

What is the magnetic declination?

Answer: 12°40′ east. (Show by figure)

Suppose the magnetic bearing of the true meridian is N 4°5′E.

What is the declination? 4° 5′ W.

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RETRACING OLD SURVEY LINES.

68. *For topographical survey work* the compass which was formerly the universal survey instrument for angle measuring, has been supplanted by the plane table (see par. 78), and the transit (see par. 71), in both of which the compass is used only to orient these instruments at the first station of the survey, that is to refer all measurements to the magnetic meridian (or the true meridian if the declination is set off) at the initial station, and to give check bearings on all azimuth readings (see par. 74). But an officer may be called upon to resurvey an area formerly surveyed with the compass; it then becomes necessary to *retrace the boundary lines of the old survey* of a reservation or other area in order to locate the old monuments as the basis of the new survey. For instance, if it were required to survey the reservation of Fort Leavenworth, it would be necessary to find the old monuments marking the boundary corners. To do this it is necessary to find the present true bearings of lines which were surveyed on magnetic bearings at some former date. All problems arising under these conditions may be most rapidly solved by drawing a figure similar to 40 assuming the position of the line on the ground and the true meridian, and determining from these the position of the old and the new magnetic meridians. Since the line itself and the true meridian are always in the same position on the ground, the measurements are to be made from them to locate the two positions of the

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magnetic meridian and thus show how it has changed since the old survey.

69. *The true azimuth of a line* is the horizontal angle which the line makes with the true meridian, measuring from the north point clockwise (to the east) around the circle. For example, the angle TOL (figure 40)=72°=the true azimuth of the line OL.

The magnetic azimuth of a line is the angle which the line makes with the magnetic meridian, meas-

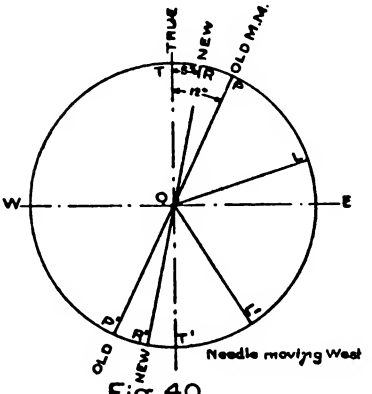

Fig. 40

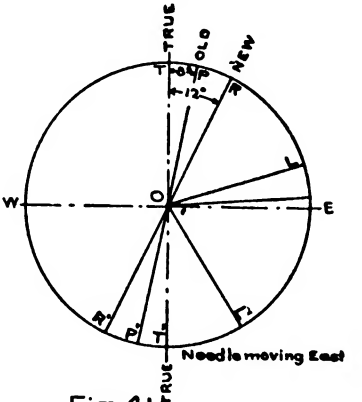

Fig. 41

ured from the magnetic north point clockwise around the circle. For example, the angle POL′ is the old magnetic azimuth of the line OL′.

The true bearing of a line is the angle less than 90° which the line makes with the true meridian. For example, the angle TOL=true bearing of line OL and is read N 72° E. Angle T′ OL′=the true bearing of OL′ and is read S 30°E.

The magnetic bearing of a line is the angle less than 90° which a line makes with the magnetic

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meridian. For example (figure 40) the angle R′ OL′=the new magnetic bearing of OL′, and is read S 35° E. By *an azimuth* is usually meant a true azimuth unless otherwise specified, and by a bearing is meant a magnetic bearing unless otherwise stated. *In the first quadrant the true bearings and azimuths are equal.*

70. *Problem 1.* The old magnetic bearing of a course is N 38° E. The old declination N 12° E. The new declination is N 5° E. What is the true azimuth of the course? (See figure 40)

Let the angle LOP=38°; the angle TOP=12°. Therefore the angle LOT=50°=the true azimuth of the line.

Problem 2. What is the new magnetic bearing of the line?

The new magnetic bearing of the line=the angle LOR=50°—5°=45°.

Problem 3. If the old magnetic bearing was S 30°E, the old declination N 12°E, the new declination N 5°E. What is the present magnetic bearing of the line? (see figure 40.)

Measuring from the position of the line OL′, assume the angle L′ OP′=30°=the old bearing; T′ OP′=the old declination=12°. Therefore L′ OT′ =30°—12°=18°=the true bearing of the line. L′ OT′+T′ OR′=18°+5°=S 23° E= the new magnetic bearing of the line.

Problem 4. If a line has an old magnetic bearing of N 50°E, the new declination is 12°E, the old declination is 8°E, what is the new magnetic bearing of the line? (Figure 41)

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Measuring from the line OL, assume the angle LOP=50°; the angle POT=8°. Therefore LOT =LOP+POT=50°+8°= 58°=the true azimuth of the line OL. LOT—TOR=58°—12°=N 46° E=the present magnetic bearing.

If the *old declination* is *not known,* it is computed from tables showing the yearly change of declination.

In case the *old declination is not known and the date of the old survey is not given,* but one end of the course is known, the other end of the course is found by running a trial line with the old magnetic bearings and using the present magnetic declination. The monument marking the unknown end of the course will be as far from the known end as is the point which has been located, and may be found by searching in the vicinity of this point just located. When this monument, of the unknown end of the course, is found the present magnetic bearing of the course is measured with the compass and the difference between the old recorded magnetic bearing and the new magnetic bearing of the line is the change in the declination from the date of the old survey to that of the new.

Problem 5. In an old compass survey the bearing of a course was N 40°23′E. The present bearing of the same line is N 41°16′E. What are the present bearings of courses in the old survey reading (a) N 89°42′E; (b) S 23°12′ W?

Solution: The magnetic declination has moved 53′ west (41°16′—40°23′) (a) This change in declination must be added to the old bearing: 89°42′

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+53′=90°35′=the azimuth from the present magnetic north. 180°—90°35′=S 89°25′E=new magnetic bearing.

(b) S 23°12′W+53′=S 24°05′W. Since the magnetic meridian has moved west at the north end, its south end has moved east, hence the 53′ is added. (Draw a figure similar to 41 to show old and new positions of magnetic meridian and the positions of the lines.)

Problem 6. The azimuths of the following courses are measured from the true meridian.

E A 35°4′; A B 111°19′; B C 201°40′; C D. 258°3′; D E 351°43′. (a) Give the magnetic bearing of each course when the declination is 8°17′ east.

Solution: E A, 35°4′—8°17′=N 26°47′ E. A B, 180°—111°19′ (to reduce to true bearings)=S 68°41′E+(8°17′)=S 76°58′E. B C, 201° 40′—180° (to reduce to true bearings)=S 21°40′W—(8°17′)=S 13°23′W. C D, 258°3′—180°=S 78° 3′W—(8°17′)=S 69°46′W. D E, 360—(351° 43′)=N 8°17′+(8°17′)=N 16°34′W. (A figure similar to 41 showing the true and magnetic meridians and the lines AB, CD etc., will indicate the method of solution.)

Problem 7. You are required to resurvey a reservation, but do not know the present declination. A line of the survey made in 1902 is recorded S 10° W. The present magnetic bearing of the same line is S 4°E.

In which direction has the declination been changing and how much has it changed?

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Answer: The declination has moved east 14°.

Problem 8. The old magnetic bearing of a line is S 89°W . The true azimuth of this line is 269° 15′. The present magnetic bearing of a second line is S 63°35′E. The present declination is 5°W.

(a) What is the difference in azimuth between the two lines?

Answer: 157°50′.

(b) The old declination?

Answer: 15′E.

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CHAPTER II.

THE TRANSIT AND PLANE TABLE.

TRANSIT.

71. *The Transit,* figure 42, *is an angle measuring instrument* with which two sets of angles are measured, one in the horizontal plane, the other in the vertical plane. *The line of the instrument which determines the direction of any point to be located, is called the line of collimation.* It is the straight line determined by the optical center of the object glass (at 0, figure 42) of the telescope, and the intersection of the cross wires, *a* figure 44.

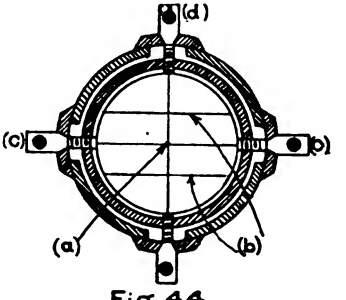

Fig. 44

When the intersection of the cross wires falls on the image of any point, this point is said to be sighted. When the telescope has two additional horizontal cross wires called stadia wires, *b* figure 44, the instrument measures distances and differences of elevation, thus completely determining the position in space of the point sighted, with respect to the location of the transit. The transit is shown and the

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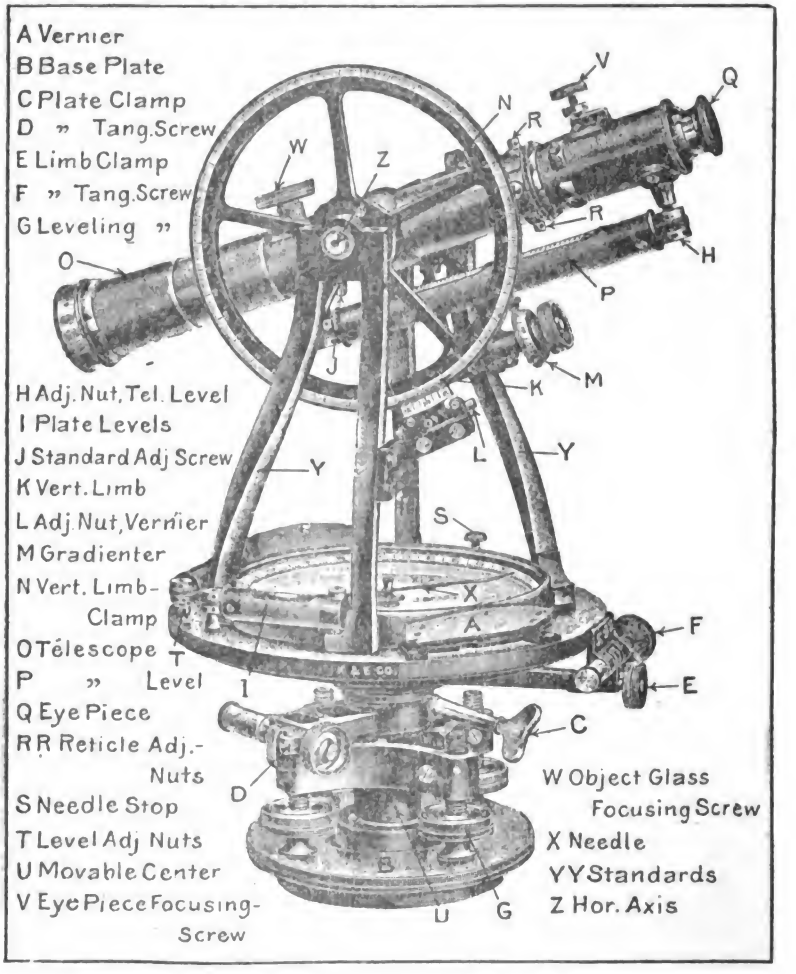

Fig. 42

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names of its parts indicated in figure 42. These parts should be learned by using a transit in connection with the figure.

The gradienter screw M allows the measurement of angles in gradients, see par. 29. The silvered edge of the head (M) is divided into 100 parts, and the screw and scale are so made as to give an elevation of 1 foot to the line of sight at a distance of 100 feet for one complete revolution of the screw.

In addition to the base plate (B, figure 42), the transit has an upper plate containing the compass circle X and verniers A. This plate rests and re-

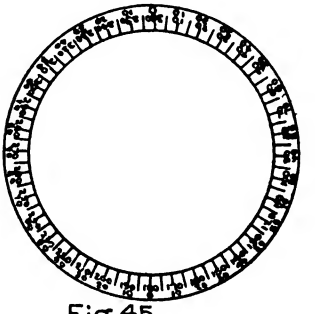

Fig. 45

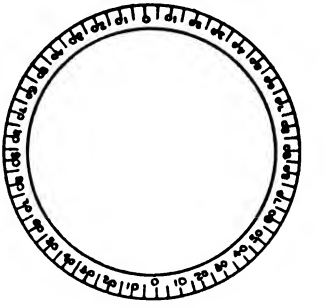

Fig. 46

volves freely in a third saucer-shaped plate called *the lower plate* which contains a horizontal circle (limb, figure 47) and is fixed in position by clamp C when the transit is oriented, for measuring angles from the meridian (called azimuths) or the angle between any two lines (difference of azimuths). Figure 45 shows a horizontal circle with two sets of graduations. The inner set of the two shown would be used.

The vertical circle K, figure 42, is for measuring

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angles of elevation or depression and is usually graduated in quadrants (up to 90°) as in figure 46.

The transit has a *compass attached to the upper plate,* fig. 47. The compass circle *a,* is graduated in quadrants like the vertical circle figure 46, or, preferably, from north around the circle counter clockwise (reading 0 at north, 90° at east, 180° at south, 360° at north). This latter style is better because the needle reading checks that of vernier A without its being first converted to azimuth from bearings. The face of the compass is also marked N, E, S, W at the positions of the north needle point when the telescope sights in those directions.

The point at which the azimuth reading on the horizontal circle is taken is indicated by the index of vernier A, figure 42; similarly for the vertical circle at vernier L's index.

72. 1. *To set up the transit*: Lift the instrument from the box by placing the hands under both plates, screw it on the tripod with the legs spread about 3 feet apart, so that when they rest on the ground the base plate B, see figure 42, will be approximately level. Attach the plumb bob to the plummet (hook underneath U). See that the clamp screws of the tripod legs, are taut enough to prevent too free a motion of the legs. Lift the transit and set it over the desired point, (just as you set down a chair) so that the plumb bob is over the stake. Force each leg into the earth firmly being careful to keep the plumb-bob over the station. Release two adjacent leveling screws G figure 42, and slip the entire upper part of the transit

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about the leveling base (base plate) until the plumb bob is over the exact station, by means of the shifting center, U. The transit is now said to be *"set up."*

73. *To level the transit*: Bring the telescope over one diagonally opposite pair of leveling screws, bring the bubbles of both level tubes to the center by turning in succession the two pairs of leveling screws, G G, so that both thumbs move towards or both away from each other. *The bubble will move in the direction in which the left thumb moves.* Rotate the alidade (telescope and upper plate) horizontally until the telescope is directly over the other pair of leveling screws and relevel if the bubbles are not exactly in the center.

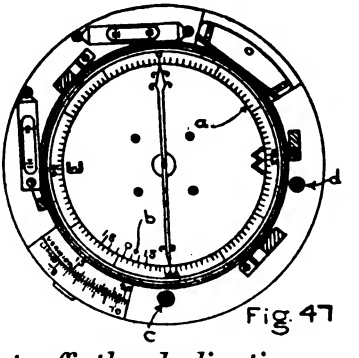

Fig. 47

74. *To set off the declination on a transit or surveyor's compass*: Move, with rack and pinion (*c*, figure 47) the north zero of the compass circle toward the declination (actual east if the declination is east and vice versa), reading the exact angle on the declination vernier, *b*. *When the declination has been set off, the readings of azimuth will be from the true meridian and the bearings will be true bearings.*

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CARE AND HANDLING OF INSTRUMENTS

75. All surveying instruments are of delicate construction and are very liable to injury if not handled with the greatest care. They should be protected from rain with waterproof sheets, and all dampness should be removed with chamois at the end of the day's work. No blows or force should be used to move any of the parts, all of which move freely if the proper clamp is released. When the instrument is set up, *only the finger tips should be used to move its parts and no weight should be placed on it.* The observer should avoid stepping close to the legs of a tripod as this throws the instrument out of level.

TRANSIT.

76. *Rules for its use and care*: The telescope and the lower clamp, C, should be released *when the instrument is being carried.* The needle should be raised from the pivot up against the glass, except when in use, by stop *d,* fig. 47. In putting the instrument away indoors the needle should first be allowed to settle naturally so that its magnetism will not be reversed, and then be raised off its pivot to avoid wear.

Never test a needle's activity with knife or other metal, as this tends to decrease its magnetism.

The object glass and eye piece (Q, figure 42) lenses should be kept constantly free from dust and grease with chamois skin or silk cloth.

To wash any part of the instrument use alcohol and chamois.

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Before adjusting the instrument make a continuous mark on the object glass ring and its slide so that the object glass can always be kept screwed up to this position in future, and that errors due to lack of uniform grinding of the lens may be avoided.

77. *Before commencing to use or adjust the transit, focus the eye piece* (Q, figure 42) by sighting on the sky and turning the focussing screw V* until the cross wires appear full and black. This adjustment should be made for each person but having been made for anyone, need not be changed again for him. Then for each sight, carefully focus the object glass with the focussing screw W until the image appears sharp and distinct; now move the eye slowly up and down in front of the eye piece always observing the image on the crosswires. If the image of the object sighted seems to shift on the crosswires, either the object glass is not focussed or the eye piece has not been properly adjusted. If several tests of the object glass do not remove this shifting of the image, readjust the eye piece and continue until no matter where the eye is placed in sighting, the image remains fixed. This shifting is called *Parallax* and when it exists accurate work is impossible. For some eyes it will be necessary to focus the eye piece so that the cross wires are not at their most distinct position, in order to remove the parallax.

*In some instruments there is no eye-piece focussing screw and the eye-piece is focussed by revolving it about the axis of the telescope.

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THE PLANE TABLE

78. *The Plane Table is a universal distance and angle measuring instrument,* especially reliable in military surveying and in its simplest form consists of a drawing board, figure 48, and ruler, figure 137, p. 243, along which lines are drawn to points sighted, and then plotted to scale.

A complete Plane Table consists of a drawing board, mounted on a tripod, with attachments as shown in figure 49. The alidade is that part of the instrument which contains the line of sight and in

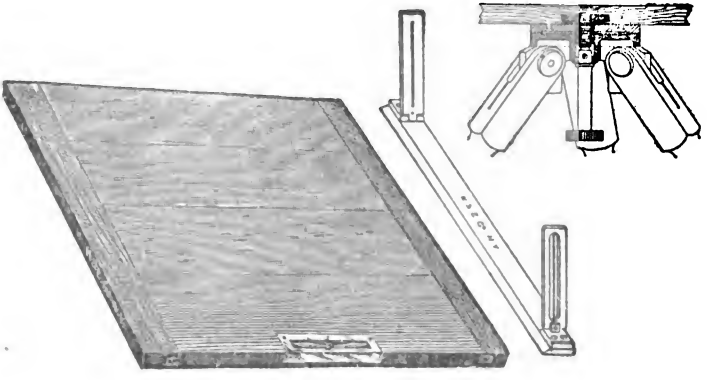

Fig. 48

the figure consists of a ruler, K, and telescope, A, connected by a vertical pedestal J. Instead of a telescope the alidade may have sighting slits, figure 48, in which case the distances to points observed must be determined by intersection, par. 156, resection, par. 155, or chaining. When there is a telescope it is usually provided with three horizontal and one vertical cross wires, figure 44, for accurately sighting any point and for reading distances on

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a stadia rod, figure 67, p. 117. The telescope is supported by the pedestal, in such a manner as to allow a free vertical motion to the telescope about its horizontal axis, for measuring angles of elevation or depression but no horizontal motion with respect to the ruler. The *Declinator or Compass Box* (P, figure 49) is used for placing meridians on the sheet and for orienting the table. The table is arranged so that it can be leveled and then rotated horizontally about a vertical axis for bringing it exactly into a desired position each time it is set up. (N) is the plumbing arm to which a plumb line is attached at the plummet (R), for centering any plotted point over a rod station stake. (LL) are level tubes for leveling the plane table. (G) is the vertical circle for measuring angles of elevation. E is the telescope level tube for assistance in using the telescope as a Wye level. S is one of the leveling screws, for making the table horizontal.

TO SET UP THE PLANE TABLE:

79. The board is screwed to the leveling head at the holes made to receive the screws. The tripod legs are opened out about thirty degrees from the vertical, so as to give a firm bearing for the table. The plane table is then set up over the station point, the legs being adjusted so that the base plate appears level to the eye. The plane table is then oriented as nearly as possible by eye and the location of the station point on the paper with respect to the station on the ground is noted. This being done the entire plane table is lifted and moved bodily until

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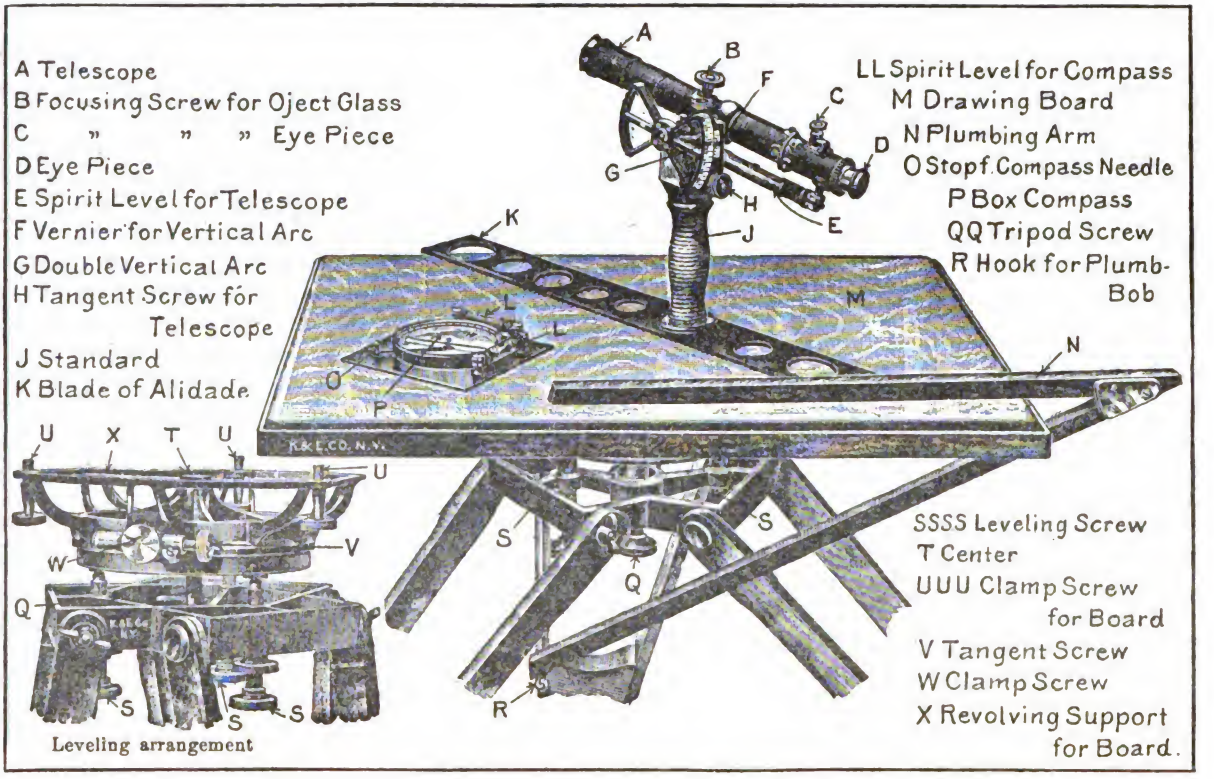

Fig. 49

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the station point is directly over the ground station. The accuracy with which the plotted point should come over its ground location depends on the nature of the work being done there. If the station is one of a traverse, par. 157, or a station for extending the triangulation, par. 148, in which errors should not be allowed to accumulate; then great care is required in locating the point, using the plumbing arm, N, and plumb line; but if the instrument is located on a station simply to plot in the details in the vicinity, then only a rough placing of the plotted point over its ground equivalent is demanded. Always keep in mind the principle that the care with which the parts of survey work are done must be graded according to the errors allowable. The more accurately each step is taken the more time is required, and often this extra time should be otherwise employed. For example, in the location of turning points, par. 134, in leveling the greatest care is demanded, whereas a reading to the nearest one tenth foot is sufficient on critical points.

TO LEVEL THE PLANE TABLE:

80. Place the compass box, P, fig. 49 (called declinator if instead of a compass box, a narrow trough is used) on the plane table. Draw lines along its edges, and by means of the leveling screws SS, bring the bubble to the center. Turn the compass box 90° horizontally, and test the bubbles. Relevel if necessary.

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CHAPTER III.

THE TESTS OF ADJUSTMENT AND THE ADJUSTMENTS OF THE TRANSIT AND PLANE TABLE.

All surveying instruments are liable to errors of adjustment, which must be corrected in order that accurate work may be done. When once adjusted these instruments will stay in adjustment for varying times depending on the care with which they are used, they should therefore be handled carefully and tested frequently.

1st. AXIS OF THE PLATE LEVELS PERPENDICULAR TO THE VERTICAL AXIS

TRANSIT

82. *Test,* I figure 42, p. 86: Level the transit (see par. 73); clamp the lower plate at C with bubble tubes parallel (and perpendicular respectively) to a diagonally opposite pair of leveling screws; revolve the alidade 180° horizontally. If the bubbles still remain in the center of their tubes they are in adjustment.

To adjust the plate levels: If the bubbles move from the center, bring them back one-half of the displacement with the leveling screws G, and

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the remainder by the bubble tube adjusting nuts, T.* Repeat the test and adjustment.

PLANE TABLE.

83. *Test*: Level the table accurately. Draw pencil lines along the edge of the compass box P, figure 49. Reverse the compass box end for end along these lines.

Adjustment: Correct one-half the displacement of the bubble by adjusting screws on the level tubes, and the remainder by releveling. Repeat until a reversal of the compass box gives no displacement of bubbles.

The first adjustment is based on the principle of doubling all apparent errors by reversal, hence the adjusting nuts are used to correct *one-half* the movement of the bubble.

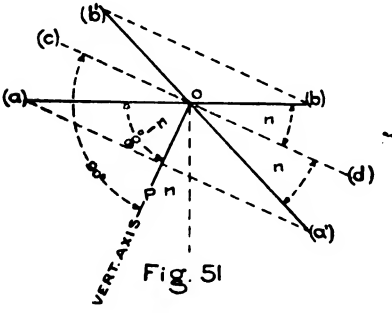

Fig. 51

Fig. 52

84. Suppose *a b* figure 51, to be the axis of the bubble tube i. e. the straight line tangent to its upper surface at the center, figure 52. Since the bub-

* To raise by means of two nuts as T figure 42, insert an adjusting pin and loosen the top nut turning the near side to the right. Then turn the bottom nut to the right and tighten it. To lower, release the lower nut by turning its near side to the left. Tighten the top nut by turning in the same direction.

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ble tubes are attached to the vertical axis of the transit if *a b* is revolved about the axis OP, it takes the position *a' b'*, and makes the angle *2n*, or twice the error, with the horizontal position of the bubble tube axis. The error of the bubble tube is the angle *n* made by *a b* with *c d*, the perpendicular to OP; but the apparent error is *a' o b*=*2n*, and this is measured by the displacement of the bubble. *When, therefore, the bubble is moved back one-half its displacement by the adjusting nuts* T fig. 42, p. 86, *a' b' is moved to the true position of the axis of the bubble tube c d* and the axis OP is made vertical by moving the bubble the remaining half of its displacement with the leveling screws, GG figure 42. If the bubble tube be reversed 180° about two fixed points of support the effect is the same as if it were reversed about an axis perpendicular to the two fixed supports. For this reason in the second adjustment of the Wye level, par. 131, the bubble is moved *one-half the displacement by means of the adjusting nuts.*

An error in this adjustment causes slight errors in the measurement of horizontal angles, because they are not measured in a truly horizontal plane. The error in vertical angles varies from zero to the angle made by the true horizontal plane with the actual horizontal plate of the instrument.

2nd. LINE OF COLLIMATION PERPENDICULAR TO THE HORIZONTAL AXIS TRANSIT.

85. *Test*: Set up the transit at O, figure 53, on fairly level ground. Sight on a well defined point

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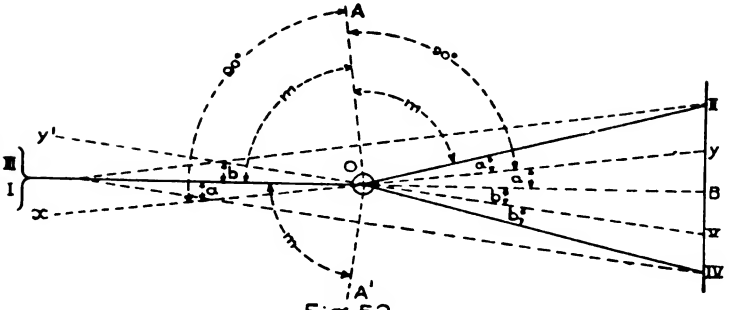

Fig. 53

as I, 200 to 400 feet distant. Clamp the lower and upper plates by C and E, figure 42. Plunge the telescope, i. e. rotate it about its horizontal axis, and have the rodman set a stake and mark with a pencil the point II now sighted at about 200 feet distant from O. Release the clamp E and revolve the telescope horizontally until I is again on the intersection of the cross wires (i. e. exactly sighted). Clamp E, figure 42. Plunge the telescope. If the point II is now exactly sighted the line of collimation is in adjustment perpendicular to the horizontal axis.

86. *Adjustment.* If instead of II some other point marked at an equal distance from O, as IV, is sighted, measure the line IV II and have a pencil mark made at V, so that IV V=¼ (II IV). With the two horizontal adjusting nuts, *c c* figure 44, p. 85, move the entire cross wire reticle horizontally until V is accurately sighted. Rotate the alidade horizontally sighting I, then plunge the telescope and if B, midway between II and IV, is exactly sighted the adjustment is complete. If not, repeat the adjustment from the beginning until all errors are removed.

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PLANE TABLE.

87. *Test and Adjustment*: Identical with that described for the transit, except that in reversing the alidade end for end the intersection of the telescope axis and the horizontal axis should be over the same point of the table in both positions.

88. The correct position of the line of collimation when I and II are sighted would be x y perpendicular to the horizontal axis A O. Angles I O x=y O II both being the angle made by the line of collimation with its true position. From the figure, angles y O B=I O x, being formed by two intersecting straight lines. In the same way B O V= V O IV; but since I O y'=I O x both being the angle made by the actual line of collimation with its true position, therefore the angle a=angle b; that is for small angles, in which the arcs are proportional to the corresponding angles, II y=yB= B V=V IV. The true position of the line of collimation, with horizontal axis in the position A′ O is y' OV. Hence when the intersection of the cross wires is moved to V, (=¼ II IV) the line of collimation is placed in its correct position.

89. *An error of this adjustment* causes a slight error in measuring angles between points at different angular elevations, because the line of collimation does not describe a vertical plane in revolving around the horizontal axis. In prolonging a straight line the error of each sight is twice the angular error of adjustment, see figure 53. *A true straight line can be run, however, with this adjustment not made,* by the method of locating II and

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IV in making the adjustment, and then bisecting the line II IV. I B is a straight line.

8d. HORIZONTAL AXIS OF TELESCOPE PERPENDICULAR TO THE VERTICAL AXIS OF INSTRUMENT. TRANSIT.

90. *Test*: Level the instrument at O, figure 54, and assume that the horizontal axis is inclined as *a a*. Sight some definite point near the top of a nearby building *x*, figure 54. Clamp both plates. Depress

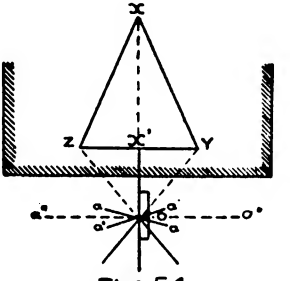

Fig. 54

the telescope until a point on the building Z, at about the height of the transit is on the intersection of the cross wires (i. e. sighted). Mark this point accurately. Release clamp E., figure 42, p. 86, and revolve the telescope horizontally 180°, bringing the horizontal axis to the position of *a' a'*. Clamp E and plunge the telescope, sighting the point *x* again and securing exact bisection with the tangent screw F, the level tube being on top of the telescope. Depress the telescope about the horizontal axis Z, figure 42 to the level of Z. If Z is thus sighted exactly, the horizontal axis is in adjustment.

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Adjustment. If Z is not thus sighted mark the point sighted, as Y, at the level of Z and the point x' midway between Z and Y. By means of the adjusting screws on one standard (J, figure 42), lower the standard on the side of the transit toward Y, figure 54, or raise the opposite one to correct the error X'Y. Repeat the test and adjustment until Z and Y coincide at x', and the horizontal axis takes the actually horizontal position a'' a''.

PLANE TABLE.

91. *Test and Adjustment*: Identical with that for transit, care being used to reverse the alidade about a point vertically under the intersection of the line of collimation and the horizontal axis of the telescope.

92. *Failure to make this (3) adjustment* causes a considerable error in measuring horizontal angles between points at different elevations. For example with the transit in its position (axis a' a'), figure 54, the error in measuring the horizontal angle between x and Y is x'OZ because the horizontal angle actually measured is ZOY, whereas it should be x'OY. Vertical angles would be slightly in error because the plane in which they are measured is not the vertical plane. For example, the vertical angle between x and Y at O, is x o x' (measured in a vertical plane), but the larger angle really measured is xOY (in the inclined plane).

Having made the 2nd and 3rd adjustments, the verticality of the vertical wire should be tested by seeing if this wire is parallel to a plumb line when

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the transit is leveled. If it is not, loosen two adjacent adjusting nuts (*d* and *c*, figure 44, p. 85,) and rotate the cross wire reticle until the vertical wire is parallel to the plumb line. The 2nd adjustment must be tested again for any possible displacement of the vertical wire horizontally.

4th. AXIS OF THE TELESCOPE LEVEL TUBE PARALLEL TO THE LINE OF COLLIMATION. TRANSIT.

94. *Test*: Set up and level the transit on practically level ground, as at O, figure 55.

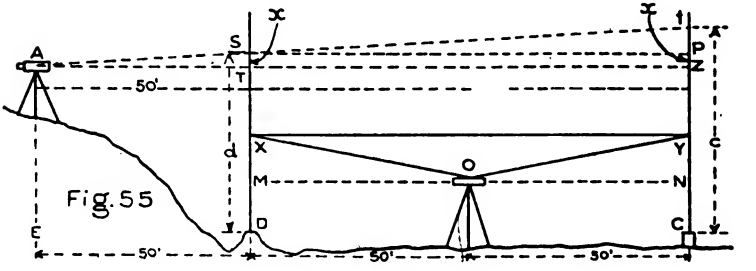

Fig. 55

Have a stake set at D and one at C, each exactly 50 feet from O and in opposite directions. Take a level reading on C with telescope bubble at the center of the tube. Then have the stake, D, driven until the target, held on it and set as read on C, is accurately bisected (bubble still in the center of the tube). The stakes C and D are then at the same elevation whether the instrument is in adjustment or not, because OX and OY are two elements of a vertical cone if not horizontal, and XM=YN= the equal altitudes of identical triangles. Move the transit and set it up at E. 50 feet beyond D from

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the direction of C. Bring the bubble of the telescope level tube to the center of its run and sight rods on D and C. If these readings are equal the bubble tube is in adjustment, since the line of collimation is parallel to the horizontal line D-C and the axis of the bubble tube is also horizontal, the bubble being at the center of its tube.

95. *Adjustment*: If the two readings are not the same, suppose the reading on D is d feet and on C is c feet, and that the change of readings required on D is x feet. Then $x=\frac{c-d}{2}$ feet. Move the target of the rod on D down or up x feet according as x is plus (+) or minus (—). The line of collimation, directed on the target of rod D, thus set, will also cut the center of the target C at the same reading and will be horizontal. Retain this pointing by clamping N, (figure 42, p. 86), and move the bubble of the attached level to the center of its tube with adjusting screws, H. Repeat the test and adjustment until the readings on D and C are the same with the bubble in the center of its run.*

PLANE TABLE.

96. *Test and adjustment*: Identical with that for transit, care being taken to see that the bubble is replaced in the same position in the tube when the

*To find the distance X which the target must be moved on rod so that the line of collimation will be horizontal when the target is sighted, and so that the reading on C will equal that on D:

Let A Z fig. 55, be the horizontal line from the center of the telescope. Then SP, parallel to AZ, is also horizontal and PZ=ST=x. The triangles AST and SPt are similar hence x:tP::50:100, or tP=2x.

$$t\mathrm{P}=c-d=2x;\ x=\frac{c-d}{2}$$

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alidade is reversed end for end, in determining the elevation of C and D.

97. *Failure to make this (4) adjustment* causes errors when using the transit as a level because the line of collimation is not horizontal when the bubble is in the center of its tube. If the fore and back sights, par. 134, are at the same distance from the transit, this error is eliminated, for the reason stated under test, par. 94.

5th. VERNIER OF VERTICAL CIRCLE TO READ ZERO WHEN LINE OF COLLIMATION IS HORIZONTAL.

TRANSIT AND PLANE TABLE.

98. *Test and Adjustment*: On completion of the preceding adjustment, with the telescope bubble in the center of the tube, make the vernier read zero by means of the adjusting nuts, L figure 42, p. 88, at each end of the vernier. If this adjustment is not made, all angles of elevation will be in error by the reading of the vernier when the line of collimation is horizontal. (See par. 245, p. 246.)

6th. STRAIGHTNESS OF THE NEEDLE AND CENTERING OF THE PIVOT.

99. *Test*: To test the straightness of the needle *n c' s*, figure 56*, and the centering of the pivot, *c'*; if at all points of the compass the north and south ends of the needle read 180° apart, the needle is straight and the pivot is properly centered. If the needle is bent as *o c z*, and the pivot is in the center, as at *c*, the difference between all north and south

*The base of the pivot is assumed to be always at *c* with its top bent over to *c'*, *c''*, etc.

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end readings will be the fixed angles *o c z*. If the difference between these needle-end readings and 180° varies from zero (with pivot at *c'''*) to some maximum angle, as 5 degrees, (with pivot at *c'* or *c*), the needle is straight but the pivot is bent.

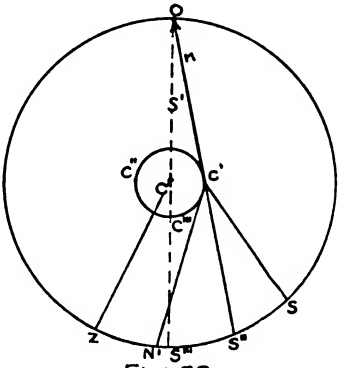

Fig 56

100. *Adjustment. Needle*: Note the readings of the north and south ends of the needle for one position (as *n* and *s*, figure 56) of the compass box. Turn the needle by hand until the south end points to the former reading of the north end (*s'*), and read the new position of the north end (*n'*). This arc (*sn'*) measures twice the error due to the bend in the needle. Remove the needle and bend it until it lies on the line *ns''*, midway between *s* and *n'**

101. *Pivot*: Turn the compass box until the difference between the end readings and 180 degrees is *greatest*. The pivot then is at *c'* or *c''*. Re-

*To remove the glass compass cover: the metal piece, holding the glass cover in place, is unscrewed in some transits; in others a split-ring above the circumference of the glass is sprung out. A split ring is used on box compasses.

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move the needle, and bend the pivot until the needle lies on the line *os'''*. (A magnifying glass held exactly parallel to the compass face should be used to get exact pointings of the needle)

7th SLUGGISHNESS OF THE NEEDLE

102. *Test*: If the needle becomes sluggish, i. e. does not move freely when the compass is level, it is due to loss of magnetism of the needle or to bluntness of the pivot.

103. *Adjustment. Needle*: Take the needle off the pivot, and hold it between the poles of a horseshoe magnet or in the field of an electro-magnet. If only a bar magnet is available, rub each end of the needle from its center toward its end with that end of the magnet which attracts in each case. The magnet at the end of each stroke should be raised about a foot to avoid opposing the magnetic field in placing the magnet on the needle again.

Pivot: If the pivot is blunt, remove the needle and grind the pivot carefully to a conical point on an oil stone.

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CHAPTER IV.

DISTANCE MEASUREMENTS.

104. *The attraction of gravitation* which causes the plumb line to be constantly directed to the center of the earth, gives the only vertical reference line in nature. The plumb line or rather a perpendicular to it (the horizontal) is, therefore, the reference line of all vertical angular measurements. Vertical angles in surveying are usually measured with the transit or plane table and in sketching with the clinometer, or by estimation.

HORIZONTAL AND VERTICAL DISTANCE MEASUREMENTS.

105. *Distances* are usually measured in the horizontal plane and in the vertical plane. Horizontal distances are meant when the term *"Distance"* is used; vertical distances are spoken of as *"Elevations,"* or "Differences of Elevation."

MEASUREMENTS OF HORIZONTAL DISTANCES.

106. Distances in topographical surveying are usually measured with the steel tape (or chain) and with the stadia, par. 117; in sketching they are measured by pacing, by the time of a horse at a walk or trot, with odometer etc., as described under that subject, Part III.

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THE STEEL TAPE AND THE CHAIN.

107. Figure 57 shows a 100 foot steel tape, reading to feet and tenths. These tapes are made

Fig. 57

by Keuffel and Esser with the tension in pounds etched on them. Each tape is standardized at 62 degrees Farenheit, and a temperature correction is

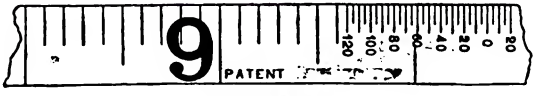

Fig. 58

etched on the 100 foot end, figure 58. At any degree of temperature at which the measurement is made, as for instance 40, use the small 40 division

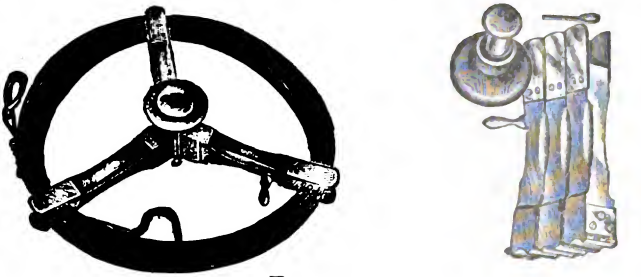

Fig. 59

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line instead of the regular 100 division for the end of the tape length. Two handles may be obtained with the tape. A more durable type of tape is the flat wire tape shown on the reel in figure 59. This one allows rougher usage and greater tension.

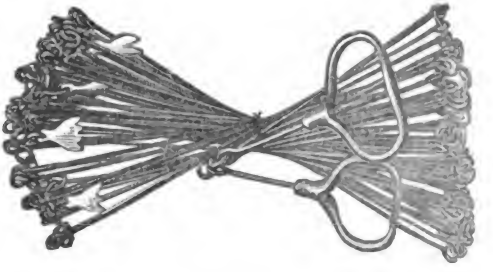

Fig. 60

Figure 60 shows an engineers' 100 foot chain. It consists of 100 links each of which, including one set of connecting rings is one foot long. Brass tags are attached at 10, 20, 30, etc. foot points, to mark decimal parts of 100 feet. These tags have different designs for each distance to avoid erroneous count; one tongue for 10 feet, two for 20, 3 for 30, 4 for 40 feet from each end.

Fig. 61

MEASURING DISTANCES.
WITH THE STEEL TAPE.

108. The two tape men are provided with eleven marking pins, figure 61, about 18 inches long. The ends of the tape should have attached to them leather handles large enough to admit the hands. The tape should be of heavy band type, figure 59, and during use should be coiled in figure of eight

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style to avoid the sharp bends necessary in winding it on a reel, which would soon break it.

The tape is pulled out along the line, figure 62, with the 100 foot mark in advance.

The rear tape man (No. 1) holds the zero mark of the tape on the initial station, A, with his right hand, and signals with his left arm the front tape man, (No. 2) into exact line. No. 2 on the left side of the tape holds the tape handle with his left hand, bracing his left elbow against his left knee and looking toward the rear tape man. His right hand holds the pin (or plumb bob on falling ground, see figure 62) opposite the 100 foot mark and, at the command *"Mark"* of No. 1, he forces the pin vertically into the ground. Both tape men move forward in tlie direction of the forward station. When No. 1 is nearly up to the pin, he calls out to No. 2, *"Steady"* and holds the zero opposite the center of the pin. The second pin is located by No. 2 as was the first. The first pin is taken up by No. 1 and thus the work continues until the 11th pin is located, when No. 2 calls out *"pins."* No. 1 records a distance of 1000 feet and carries up his ten pins giving them to No. 2. Each pin taken up by No. 1 adds 100 feet to the measured length. If a fractional part of the tape length is to be added at the end, No. 2 pulls out the tape full length, walks back to B and reads the number of feet on the tape at B. The number of pins located including the last one are counted and the number of feet beyond the last pin are added.

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109. *The total distance* would be as follows: Number of times No. 1 took up the ten pins, times 1000 feet; plus the number of pins held by No. 1, multiplied by 100 feet; plus the number of feet beyond the last pin to B. *The error due to expansion or contraction* of the tape is accumulative. It is plus if the temperature is greater than that at which the tape is standardized. Tapes are usually standard at 62 F. and for a 100 foot tape *a change of 30° F. changes the length ¼ inch.* This rule is used as follows. If a base is measured at 77° F. the tape would be 100 ft+$\frac{15}{30}$[½(¼inch)] feet=100.01 feet long. (Explanation: $\frac{15}{30}$ reduces correction to feet. 77—62 = 15° above normal temperature, hence ¼ inch must be multiplied by $\frac{15}{30}$ or ½) Tapes should have the temperature correction as in figure 58. *The error due to setting pins and lack of uniformity of pull* are compensating, that is they have a tendency to balance each other. It is found in surveying that one of the most frequent sources of error is in erroneous tape or chain measurements, therefore too great stress cannot be laid on the necessity for accuracy in this work.

On sloping ground a plumb line should be used to determine the exact end of the tape, figure 62. If the slope is irregular and too great for the plumb line held by the tape man to reach from the end of the horizontal tape to the ground, fifty or 25 foot lengths are used. The greatest care is required to

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add the fractional tapes correctly. Where the ground slopes uniformly, the measurements may well be made along the surface and converted to the horizontal distances by the formula C B=DB cos *a*=correct horizontal distance. DB=distance along the slope, *a*=angle of slope, figure 62.

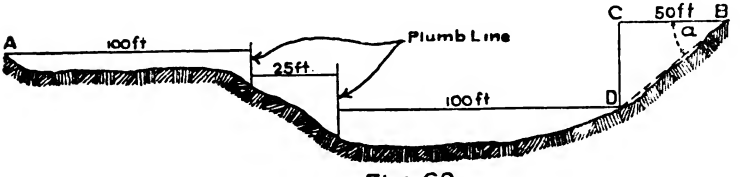

Fig. 62

110. *Cautions*: *See that there are no kinks in the tape.*

Have the tape horizontal.

Insert each pin exactly vertically in the ground. If a pin is dropped to get the exact point, it should be dropped with the ring down.

Do not pull horizontally on a pin once stuck. The tape men brace the elbow against a knee to keep the tape in position.

Test the tape before measuring a base line by comparing it with an accurate standard. If it is too short or too long, *the true distance is found by multiplying its actual length by the number of tapes in the line.*

RANGING OUT A LINE.

111. *To range out a line between two mutually visible points,* as A and B, (figure 64), tape man No. 2 takes position between A and B, and No. 1

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Fig. 64

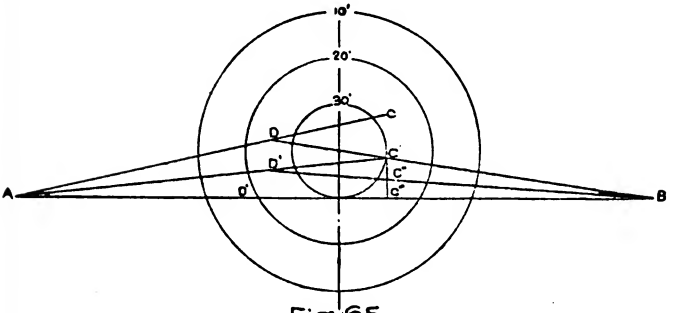

Fig. 65

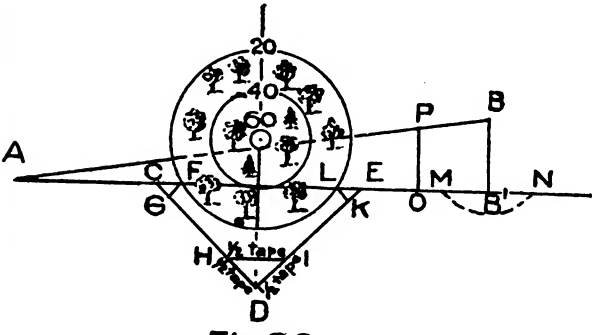

Fig. 66

Fig. 63

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beyond the A end of the line signals No. 2 until his flag or range pole, figure 63, is in line with A and B. No. 2 sets his range pole vertically in the line and proceeds farther toward B setting a second range pole as before. With two poles in the line, No. 2 can line in successive poles by bringing the third into the line established by the other two.

112. *To line in when the observer and an assistant are between the two points* determining the direction of the line as A—B, figure 65, or when these points are mutually invisible from each other, proceed as follows: The observer at C places himself as near the line as possible and directs the assistant at D into line with A D, then the assistant directs C into line with B, as at C′. Thus by two or three repetitions C is placed on the line A B.

113. *If the observer is alone* between A and B, figure 65, he can place himself in line with A and B by laying a pole so as to point toward A from his position C, as CD. Then going to D, he points the pole toward B as DC′, and so on until the pole lies in the required line.

METHOD OF PASSING OBSTACLES WITH TAPE OR CHAIN.

114. If A and B, figure 64, are mutually visible, measure from A to a point, as C, near the obstacle, and from B to a similar point, as D. At C construct a right angle by laying off GC 30 feet long; with a 50 foot length held at G as a pivot cut the arc as shown; similarly with the 40 foot length

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pivotted at C cut an arc at H. A line through C and the intersection of these two arcs at H gives a right angle at C. (The triangle whose sides are in the proportion of 3:4:5 is right angled) Measure C E, long enough to clear the obstacle. At D lay off similarly a right angle and measure D F= C E. Measure E F=C D. If not convenient to measure from B to D, right angles would also be constructed at E and F by the same method.

115. 2nd. If B is not visible from A on account of an impassable object, and the direction of B from A is not exactly known, figure 66: Range out the line A C as nearly in the given direction as can be estimated. Measure A C. At C construct the equilateral triangle C F G, by laying off C F=$\frac{1}{2}$ tape (or chain) in the extension of A C, and holding the two ends of the tape at C and F pull out the middle point taut to G. Range out and chain C G to D from where the obstacle will be cleared as shown. Construct on H D equilateral triangle H D I; measure D E=C D; on K E construct equilateral triangle E K L. Measure E B′ which is the extension of A C. With B as a center and a tape or cord of suitable length describe an arc cutting the line E B′. Bisect this line M N at B′, par. 202. The line B B′ is perpendicular to A B′. Then $A\,B=\sqrt{B\,B'^2+A\,B'^2}$. Points on A B may be located on the ground by erecting perpendiculars at various points, as O, and on these laying off distances, as O P, by the proportion: O P:B B′ :: A O : A B′. The line A B can now be cut through the wood if desired.

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STADIA RODS.

116. One of the best types of Stadia Rod is shown in figure 67. They are used in connection

Fig. 67

with the telescope of the Plane table or transit for reading the distances from the instrument to any point sighted. These rods are about 12 feet long, 4 inches wide and $\frac{5}{8}$ inch thick of white pine.

STADIA MEASUREMENTS.

117. *The distance to any point* is read, in plane-table and transit surveys, by observing how many divisions of the image of the stadia rod placed on that point are included between the upper and lower horizontal wires of the telescope. The farther the stadia rod is from the telescope the greater are the number of divisions of the image of the rod between the stadia wires.

If, instead of the telescope, a single peep hole, O, figure 68, were used through which to observe

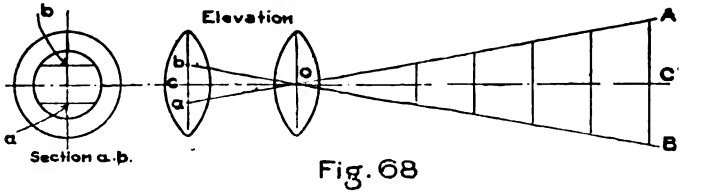

Fig. 68

the rod, then it is evident that the portion of the rod intercepted between *a* and *b* would be exactly proportional to the distance of the rod from the

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peep hole. This is seen from a consideration of the similar triangles B A O and *b ao, ba*: O *c*: : AB : OC, or $\frac{ab}{Oc}=\frac{AB}{CO}$ but since $\frac{ab}{Oc}$ is a constant quantity, (both *ab* and *Oc* being fixed values), AB is always directly proportional to OC. Or as the intercept (AB) increases, the distance (OC) increases in the same proportion. However, in order to secure sufficient enlargement of the image so that the divisions on a rod several hundred feet distant may be plainly seen, it is necessary to use a telescope with magnifying lenses. It is a well established *Law of Lenses* that, due to the bending of rays of light passing through the lenses, the length of the spaces on the Rod between the points cut by the upper and lower stadia wires of the telescope, *is proportional to the distance of the Rod from a fixed point in front of the telescope,* as D, figure 69.*

That is to say the rod at G has the intercept B′ C′; at H, the intercept BC etc., the number of feet of each intercept being exactly proportional to the

*The law of lenses above discussed is expressed mathematically by the equation $\frac{1}{f'}=\frac{1}{f}-\frac{1}{f''}$ ...(1), in which f' is the distance in rear of the object glass at which the image of the target held at a distance f'' in front of this lense, is brought to a focus. f' and f'' are called **Conjugate Focal Distances.**

From equation (1) it can be shown mathematically how a rod can be correctly graduated to give true distance readings and how readings up or down a slope are reduced to true horizontal distances and true differences of elevation. The practical methods only of doing these things will be given, and those who are interested in mathematics will find the mathematical solution in any treatise on general surveying.

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number of feet of the stadia rod from D. If DG =100 feet and B′C′=1 foot, then at H (DH= 200 feet), BC would equal 2 feet and the distances 100 feet and 200 feet are said to be *read from the rod* at G and H respectively. Therefore to obtain correct distances from the center of the instrument to the rod as O G′, the fixed distance OD′ must be added to each distance read from the rod. The

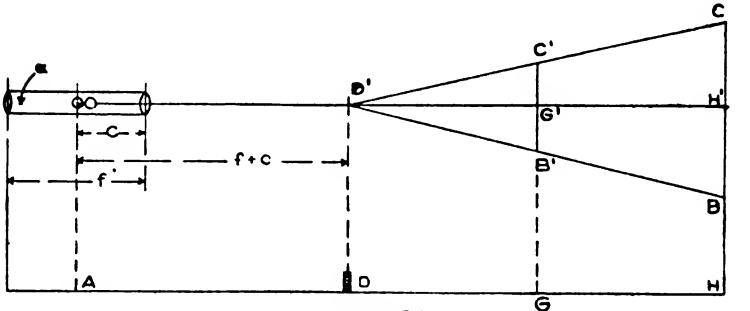

Fig. 69

distance AD, (=OD′) of D from the center of the telescope, is equal to the fixed quantity (c+f) in *which c=the distance of the object glass from the center of the horizontal axis of the telescope, O, when focussed at the average length of sight, and f is the principle focal distance of the object lens,* that is the *distance in rear of the object glass at which parallel rays are brought to a focus.* *f* may be found by measuring the distance from the object glass to the plane of the cross wires when the telescope is focussed on some object ½ mile or more distant. However, it is a general custom nowadays for telescope cases to have the value of (*c*+*f*)

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printed thereon by the maker, for use in case a stadia rod is to be graduated.

METHODS OF GRADUATING STADIA RODS.

118. 1st. *To graduate a rod to give true distances from the apex D*: Set up the instrument on level ground at A, figure 69. Drive a stake at D=($c+f$) feet from A. Measure D H=400 feet and mark on the rod on H with pencil, as directed by the observer, at B and C the points cut by the upper and lower stadia wires. This space B C on the rod is divided into 4 equal parts each of which is the reading per 100 feet from D. Now lay off these values ($\frac{1}{4}$ B C) corresponding to 100 feet from the bottom of the rod to the top, dividing each into 20 equal parts each representing 5 feet, by horizontal lines across the rod. The rod should be first painted white and then the selected design painted on it in black. The design of the rod, figure 67, is best because of the ease with which the hundreds, fifties, twenty-fives, tens and fives are distinguished. The hundreds are two masses of black separated by a diagonal white line. Fifties are at the large white salient angle; twenty-fives and seventy-fives are the longest horizontal masses of black, tens are white indentations, fives are black and white points. To each distance as read from the rod, the value of ($c+f$) is added before plotting it; to show the distance from the center of the instrument.

2nd. *To read distances on a rod already graduated into feet and tenths*: Read from the rod the value of B C corresponding to 400 feet, figure 69.

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Divide 400 by B C, this quotient is a quantity by which each rod reading must be multiplied to give true distance from D. For example, suppose B C figure 69, is 3.96 feet, then $\frac{400}{3.96}=101.01$. Now if the reading on the rod (actual space) should be 7.67 feet; $7.67\times101.01=774.75$ feet on ground. Suppose $(c+f)=1.00$ foot. Add this value and there results, $774.75+1=775.75$ feet=correct distance from the center of the instrument to the rod. It is evident that this is a slow method, since a multiplication is required for each reading, whereas on the rod as graduated under the first method no multiplication is necessary. This method would only be used in an emergency where no time is available to graduate the rod.

3rd. *To graduate the stadia rod to read distances from the center of the instrument*: Measure, on level ground, 400 feet from the center of the instrument, A to H figure 70. Divide the inter-

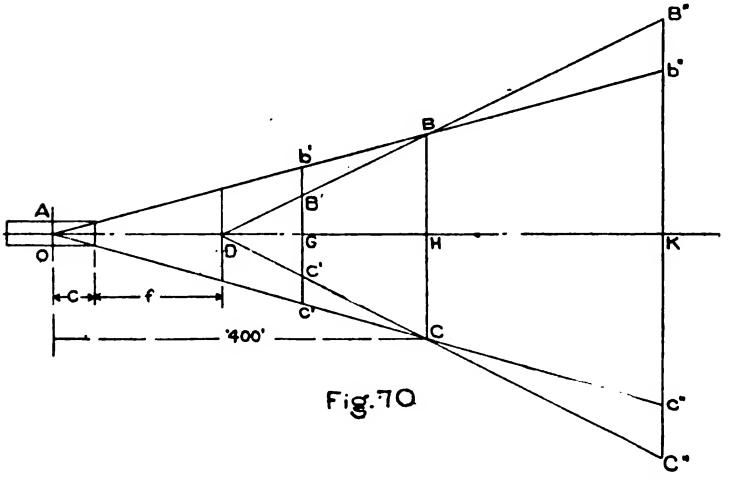

Fig. 70

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cept B C (actual space) on the rod into 4 equal parts and lay these off on the rod, as under first method, for 100 foot readings. These readings would be strictly correct only for a 400 foot distance, from the center of the instrument, for shorter distances somewhat too small and for greater distances somewhat too large, as shown in the figure.

The rod intercepts are actually limited by the sides of triangle B″ D C″, figure 70, whereas they should be limited by the sides of triangle b'' A c'' to be correct distances from the center. Evidently the intercept (B′ C′) on a rod held at G indicates too short a distance because the rod intercept would have to be b' c' to indicate correctly the distance O G.

For filling in detail on military surveys of small areas, these readings would be sufficiently accurate. No $(c+f)$ would be added to the rod readings, and some time would thus be saved.

119. *To place on the rod the value of the intercept corresponding to the horizontal distance of* $c+f$ (*b* figure 67, p. 117): Having graduated the rod by the first method above, find the space on the rod corresponding to $(c+f)$ on the ground and paint this space *both above and below* every 100 foot mark, as shown at *b*. For example, suppose $(c+f)=1.25$ feet and that the space on the rod corresponding to 100 feet from D, figure 69, equals 1.15 feet. Then one foot on the ground$=\frac{1.15}{100}$, and

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1.25 feet on the ground $=\frac{1.15\times1.25}{100}=0.01437$ feet on the rod or .17 inch. The width of the spaces corresponding to 2 $(c+f)=.34$ inch. To add $(c+f)$ to each reading, the lower wire should be placed along the top edge of the $(c+f)$ space instead of on the even hundred mark (see figure 67). Thus, when the reading of the top wire is taken, it is $(c+f)$ greater than that corresponding to the intercept between the stadia wires.

HORIZONTAL DISTANCES AND DIFFERENCES OF ELEVATION FROM INCLINED STADIA READINGS.

120. The rod, as graduated above, gives correct distances only when the line of collimation is horizontal, but on sloping ground it is necessary to place the telescope in some such position as A′ D′, fig. 71.* When the stadia rod is read with the line of collimation thus inclined up or down, as A′ B′ figure 71, an intercept *m n*, on the rod inclined to the line of sight is read instead of *s p* on the rod perpendicular to the line of sight. Formulas may be worked out giving the horizontal distance H and the difference of elevation C between the two

*Vertical Angles should always be read while the line of collimation is parallel to the line joining the instrument station (A) and the rod station (B) so that the difference of elevation determined (between A′ and B′), will be that required, between A and B. This result is accomplished by measuring the height of the horizontal axis of the telescope above A (H. I.), placing an elastic band on the stadia rod at this height, and sighting this band previous to reading the vertical angle.

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points on the ground A and B from the readings such as *m n*. These formulas are:

$H=(c+f)\cos a+s\cos^2 a.$ (1)

$C=(c+f)\sin a+\frac{1}{2}s\sin 2a$ (2)

$(c+f)$=*the distance from the center of the instrument, A′, to the apex D′ along the line of sight,* see figure 71.

a=angle of inclination of the line of sight.

s=number of feet (D′B′) *corresponding to m n on the rod held vertical.*

In formula (1), $(c+f)\cos a$=*horizontal distance* A′ E *corresponding to the inclined distance* $(c+f)$.

$s\cos^2 a$=*horizontal distance* D″ B″ *corresponding to the inclined distance* D′ B′.

In formula (2), $(c+f)\sin a$=*the elevation* E D′ (=F G) *the elevation corresponding to the inclined length* $(c+f)$.

$\frac{1}{2}s\sin 2a$=B′ F *the elevation corresponding to the inclined line* D′ B′. B′ F+F G=B B″=*difference of elevation between* A and B.

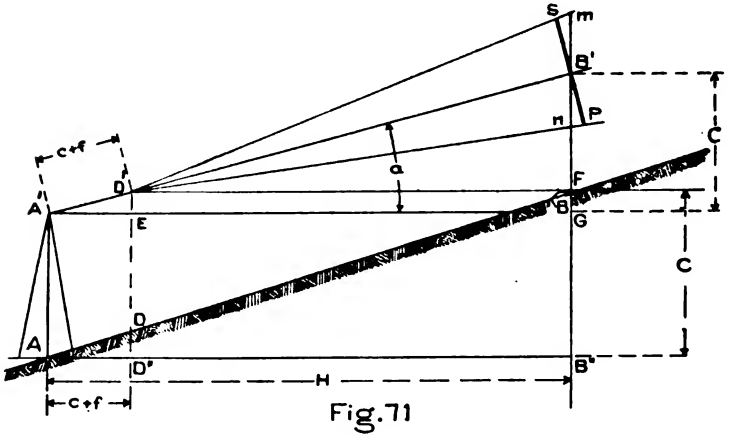

Fig. 71

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121. To find the horizontal distance or difference of elevation from A to B by these formulas will require a slow tedious solution of the equations for every reading, making it impracticable to get the desired results. To obviate this difficulty, table I Appendix has been arranged showing the solution of the formulas for all cases usually required. The first terms of the equations are tabulated at the foot of the table; the second terms in the main columns Hor. Dist. and Diff. Elev.

Rule: *To obtain correct horizontal distances*: Read the number of feet corresponding to the stadia rod intercept, and multiply the number of *hundreds* of feet in this distance by the number, in the Hor. Dist. column opposite the angle of slope, which is the horizontal distance for a 100 foot rod reading. To the result add the value corresponding to the $(c+f)$ correction at the foot of the horizontal distance column. For example, suppose the stadia reading 397 feet, slope $+14°10'$. $(c+f)$ for the instrument used=1.00 foot. Find opposite $14° 10'$ the value 94.01. $3.97 \times 94.0 = 373.18$.

Opposite $c+f$ (1.00), find 0.97. $373.18+0.97 = 374.15$=correct horizontal distance.

122. *To find the difference in elevation between the instrument station and the rod station*: Opposite the angle of slope in the Vert. Dist. column find the difference of elevation for a reading of 100 feet on the rod. Multiply this number by the number of hundreds of feet indicated by the intercept on the rod. Add to the product, the $(c+f)$ correction at the foot of the column Diff. Elev., for

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example: With the rod reading 397 feet, pick out opposite 14°10′ in the column Diff. Elev. 23.73. $3.97 \times 23.73 = 94.20$. Pick out at the foot of Diff. Elev. column opposite $(c+f)=1.00$, correction 0.25; $94.20+.25=94.45$ feet=correct difference of elevation. Add this to the elevation of the instrument station for the required elevation of the rod station. Comparing these results with those obtained with the Cox Stadia computer, figure 72 (see par. 123), shows the errors probable in using the computer. There is an error of about 1 foot horizontally and .2 foot vertically. This is well within the limits of accuracy of the stadia readings and shows that the computer may be used in all filling in work. It must, however, be used with care. The reductions can be made in about $\frac{1}{5}$ the time required for the table when made with the computer.

STADIA COMPUTER.

123. Figure 72* shows a Cox's Stadia Computer, with which horizontal distance corrections and differences of elevation, from rod readings on slopes, are determined mechanically with far greater rapidity than is possible with the stadia reduction table, appendix I. The stadia computer is used as follows: Set the index (zero) of the wheel at the stadia reading, and opposite the angle of slope from instrument to rod, read off the correct distance on section *"Hor. Dist."* and difference of elevation on section *"Difference of Elevation"* on the outer circle. For example:

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COX'S STADIA COMPUTER.

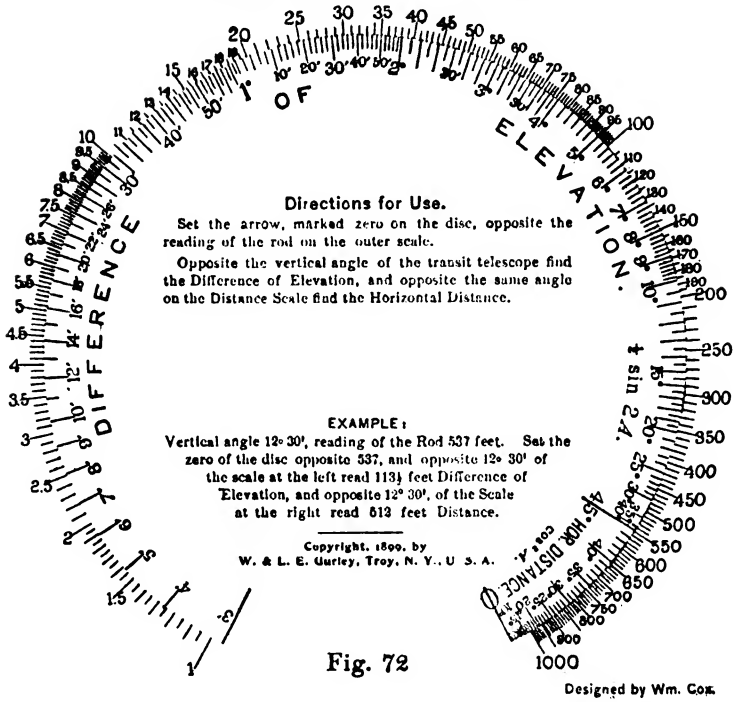

Fig. 72

Designed by Wm. Cox.

Assume a stadia reading of 397 feet; vertical angle, $+14°10'$; $c+f=1.00$. Set the zero (index) of the inner circle opposite 397 of the outer circle. Opposite $+14°10'$ find on the Elev. scale of the outer circle 94.00. Add correction for $(c+f)=0.25$ (found in the small table on the computer, not shown in the figure) $94.0+.25=94.25$ feet, to be added to the height of the instrument station.

On the Hor. Dist. scale, opposite $14°10'$ find 372.0. Add c+f correction .97. $372+.97=372.97$ feet total distance horizontally of the rod from the instrument station.

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CHAPTER V.

THE WYE LEVEL.

124. *The Wye Level* shown in figure 73 is an instrument designed for accurately determining differences of elevation between points on or near the Earth's surface. The sighting line of the instrument is determined by the *line of collimation of the telescope, which is the straight line joining the optical center* (practically the actual center) *of the object glass and the intersection of the cross wires, a* figure 44, p. 85. When the intersection of the cross wires is exactly on the image of the point, it is said to be sighted. The essential parts of the Wye Level are shown in the figure. V is the tangent screw for giving the instrument small horizontal motion after it is clamped in position by clamp W.

THE LEVEL ROD.

125. There are several kinds of level rods made, but the one most generally used is the *New York Rod,* figure 75. It is a target Rod, reading 6.5 feet on the vernier of the target when folded and from 6.5 to 12 feet on the side vernier when extended. There is a set screw to clamp the two parts of the rod together at any height. To read above 6.5 feet the target is set at 6.5 and the rod extended until it is bisected by the horizontal cross wire. The rod is

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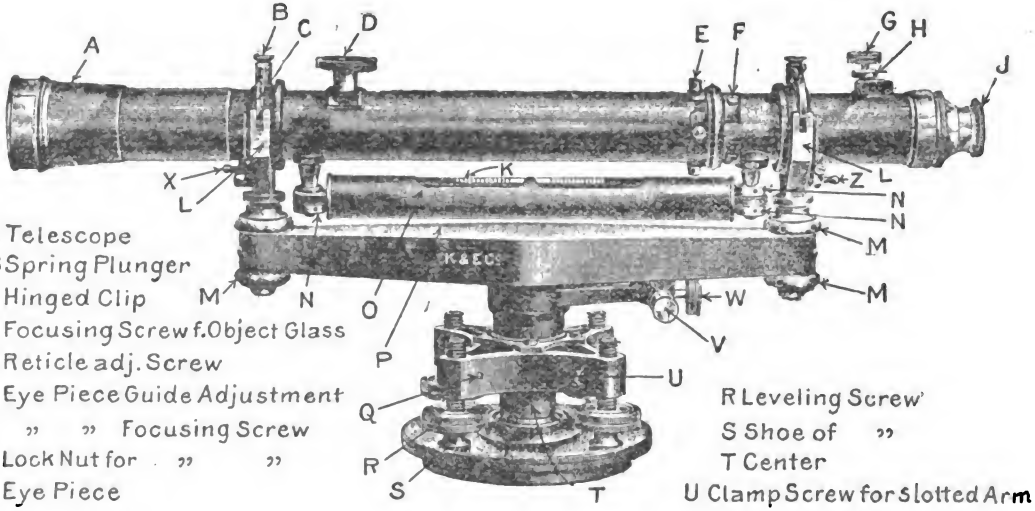

Fig. 78

A Telescope
B Spring Plunger
C Hinged Clip
D Focusing Screw f. Object Glass
E Reticle adj. Screw
F Eye Piece Guide Adjustment
G " " Focusing Screw
H Lock Nut for " "
J Eye Piece
K Spirit Level
LL Y's
MMM Adj. Nuts for Y's
NNN " " " Spirit Level
O Spirit Level Tube
P Bar
Q Leveling Arms
R Leveling Screw
S Shoe of "
T Center
U Clamp Screw for Slotted Arm
V Tangent Screw
W Clamp for Center
X Locking Device for Y's
Z Adjustable Stop f. Telescope.

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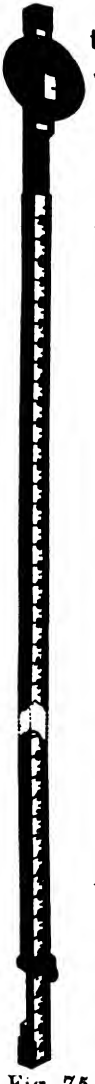

Fig. 75

graduated in feet, tenths and hundredths, the least reading being .001 foot on the verniers.

For rapid work in which the greatest accuracy is not required a speaking rod graduated into feet and tenths with designs like the stadia rod, figure 67, p. 117, may be used. With a speaking rod, the observer reads through the telescope the rod at the point indicated by the horizontal wire.

126. *To set up the Wye Level*: Remove the instrument from its box and screw the base plate below T, figure 73, to the tripod head; place the telescope carefully in the wyes. Secure the clips CC; release clamp W, and the instrument is ready for use. The level need not be set up over any exact point in leveling consequently no plumb line is furnished. Separate the tripod legs about 30 degrees from the vertical and force them firmly into the ground, until the base plate appears level to the eye.

127. *To Level the Instrument*: Revolve the instrument head (containing the telescope) horizontally until the telescope is exactly over a diagonally opposite pair of leveling screws R. Rotate these screws with thumbs and forefingers, moving both thumbs either toward or away from each other, until the bubble stands at the center of the tube. Repeat with the telescope over the other

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pair of leveling screws. The bubble should now remain in the center of its tube when the instrument head is revolved completely around its vertical axis. If it does not do so relevel as just described. If the bubble can not by careful leveling be made to remain at the center, the instrument is out of adjustment.

128. *To Focus the Eye Piece and Object Glass*: Before commencing to use the instrument, the eye-piece should be focussed on the cross wires for the eyes of the observer. To do this, point the telescope at the sky and looking through the eye end of the telescope at the cross wires, turn the eye piece focussing screw, G, until the cross wires are most distinct and black. When this is done for one pair of eyes the screw G should not be touched again while this person alone continues to use the level.

129. *To sight any object as the level rod*: Point the telescope at the rod and looking through the eye end, turn the object glass focussing screw D, until the rod appears sharp and distinct. Now slowly move the eye up and down before the eye piece, and the image of a particular point of the rod should remain fixed in position on the intersection of the cross wires. If it does not, the focus is not correct; refocus the object glass and retest. If there is still displacement of the image, refocus the eye piece and so on until the rod is seen without the least displacement on the cross wires. This displacement is called parallax and is fatal to accur-

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ate work unless removed. For some eyes it will be necessary to adjust the eye piece so that the cross wires are not exactly at the most distinct position, in order to remove the parallax.

TEST AND ADJUSTMENT OF THE WYE LEVEL.

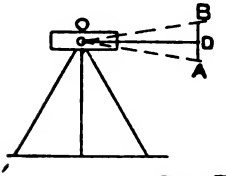

Fig 77

130. 1st. *Line of Collimation* (see par. 124) *Parallel to the axis of the Bearing Rings.*

Test: Sight some distinct point as a tack head, A, figure 77, release the clips (holding the telescope in its rings) and revolve the telescope 180° about its own axis. Direct the telescope toward A, if the tack is still accurately sighted this adjustment is correct.

Adjustment: If another point, B, is sighted, mark at the point midway from B to A, as D, and place the intersection of the crosswires on this point by moving the reticle with screws *c* or *d*, figure 44, p. 85. If B is obliquely above or below A, the reticle must be moved both horizontally and vertically to sight the point D.

131. 2nd. *Axis of Bubble Tube in a Horizontal Plane Parallel to that containing the Line of Collimation.*

Test: Place the telescope over two diagonally opposite leveling screws and clamp it there. With these screws R, figure 73, bring the bubble to the center of its tube, release the clips C, gently lift out the telescope and turn it end for end. If the

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bubble retains its position at the center, the adjustment is correct (see under transit, par. 84).

Adjustment: If the bubble moves from the center, bring it back one half the distance by means of the leveling screws R and the remainder by means of the upper and lower adjusting nuts N, figure 73. Repeat until it remains at the center.

132. 3rd. *Axis of the Bubble Tube in a Vertical Plane Parallel to that containing the Line of Collimation.*

Test: Having made the preceding adjustment and with the bubble at the center of its tube, rotate the telescope around its axis about 15°. If the bubble remains at the center the adjustment is correct.

Adjustment: If the bubble moves from the center, bring it all the way back by means of the horizontal adjusting nuts at one end of the tube. Repeat this and the preceding adjustment until both are correct. Since the 2nd and 3rd adjustments bring the axis of the bubble tube into two planes both parallel to the plane containing the line of collimation, therefore the axis of the bubble tube is parallel to the line of collimation.

The preceding adjustments are the only absolutely essential ones, because now, if the bubble is at the center of its tube (which can be verified by observation), the line of collimation must be horizontal.

133. 4th. *Axis of the Wyes Perpendicular to the Vertical Axis of the Level.*

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Test: Place the bubble in the center of the tube with the telescope over a pair of diagonally opposite screws; revolve the telescope horizontally 180°. If the bubble remains in the center of its tube the adjustment is correct.

Adjustment: If the bubble moves from the center, bring it back half way by means of the leveling screws, and the remainder by means of the adjusting nuts M.

The 4th adjustment is not essential, but convenient to avoid the necessity of releveling when the telescope is revolved horizontally. Since the leveler determines the horizontality of his line of sight by placing the bubble in the center of the tube, *it is of the greatest importance that the 1st and 2nd adjustments are correctly made.* They should be tested every day. The Wye adjustment (4th) is convenient but does not affect the accuracy of the work if the bubble is accurately brought to the center of its run for each sight on a turning point. If the line of collimation is not parallel to the axis of the bubble tube errors occur except for back sights and fore sights of exactly equal length (see par. 94 and figure 55, p. 103).

METHOD OF USING THE WYE LEVEL.

134. *A Bench Mark* (B. M.) is a specially selected or prepared point on the ground whose elevation is known or assumed with reference to some datum plane (see par. 22), and to which are referred the elevations of other points whose elevations are unknown. Any permanently fixed ob-

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jects such as stone coping, concrete pillar etc., may be used as B. M.'s. A *Turning Point* (T. P.) is a temporary B. M., so called because it is used as a reference point of elevations while the instrument is moved or turned from one station to another. It may be marked by a turning pin, figure 78, or a stake.

An Instrument Station, as station I, figure 79, is the point on the ground where the level is set up. It need not be in the straight line joining the known and unknown points A and B. A Rod station as C, 1, 2, etc., is a point where the rod is held for securing the elevation.

A Back Sight (B. S.) is a plus (+) reading on the rod held on a point of known elevation (as A) to obtain the height of the line of sight of the telescope, (called the height of the instrument or H. I.) *above* that point. A *Fore Sight* is a minus

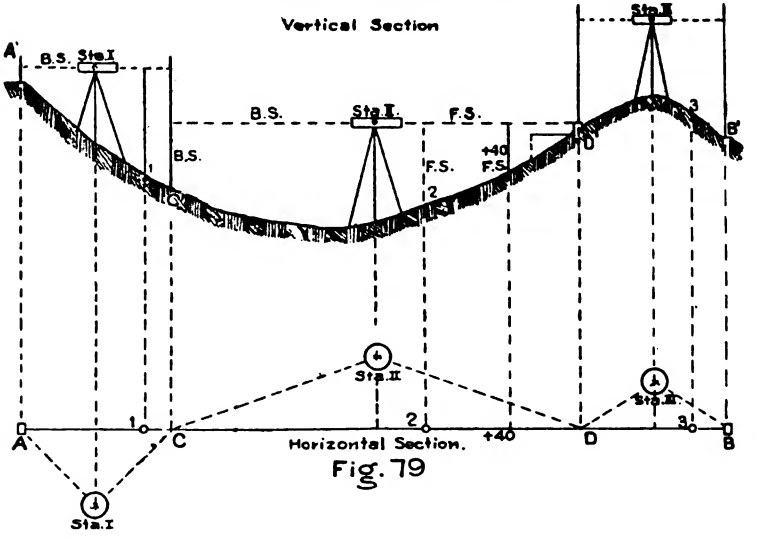

Fig. 79

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(—) reading on the rod held on a point of unknown elevation as 1, 2, etc., figure 79, to determine its elevation, measuring *down* from the known height of the instrument.

The wye level is used in connection with a plane table survey for determining the elevation of the ends of the base, and frequently that of the triangulation stations.

DIFFERENTIAL LEVELING.

135. *To find the elevation of one point* (B) *with respect to another point* (A) whose elevation is known or assumed, figure 79.

The observer sets up and levels the instrument at station I, at which the axis of the telescope is higher than point A (located from a B. M), and directs the rodman to move the target of the level rod held exactly vertical on A, up or down until it is bisected accurately by the horizontal cross wires.*

*The Rodman standing directly behind the rod should hold it lightly with one hand, while moving the target up or down with the other as required. To enable the observer to determine when the rod is vertical (not inclined to front or rear) the rodman waves the rod slowly back and forth, figure 80. If at any point of the instrument, the zero of the target appears to rise above the horizontal cross wire, as at *c*, the rod was not being

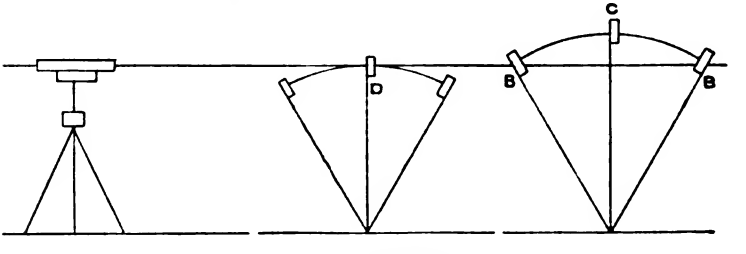

Fig. 80

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The rodman then reads and records the reading of the rod at zero of the target vernier, figure 81, and moves to station I (counting paces), where his rod reading is checked by the observer.

The rodman then moves to C (turning point) counting as many paces as he took from A to I.

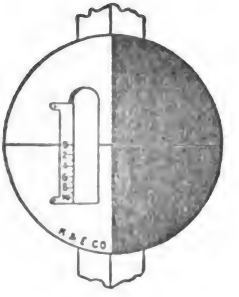

Fig. 81

Fig 78

At C the rodman drives a turning pin, figure 78, or a stake, and a rod reading is taken at this point as explained for A. The observer now moves to some convenient place as station II, so located that the level here will give a reading on the 1st turning point (C) and on a second turning point (D)

held vertical when the target was set as at B. This test should be made at every T. P., and the zero of the target at its highest point made to appear tangent to the center horizontal wire, as at D. An angle target, figure 81 shows when the rod is vertical.

A motion of the arm above the hip palm up, means to elevate the target; below the hip palm down, to depress it. A rapid movement of the arm means to move the target a foot or more; a slow movement of the arm means to move the target slowly but continuously until the signal to stop is given by a horizontal motion of the arm. Both arms waved means "clamp." The arm held outstretched obliquely means to incline the rod in the direction of the palm. All yelling from the observer to the recorder indicates lack of systematic control of the work.

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in the general direction of the required station B, but not necessarily in the straight line A B *(T. P.'s need not be in the profile line)*. These steps are repeated until a F. S. is taken on the point B whose elevation is required. The record is kept as follows:

FORM OF RECORD FOR DIFFERENTIAL LEVELING.

136. (See figure 79)

Instrument men——— *Place*———

Rodmen——— *Date*———

Station Observed	Elevation	B. S. +feet	H. I. ft.	F. S. —feet	Remarks
B. M. A	800	1.249	801.249		Elev.+BS=H. I. 800+1.249=801.249
T. P. I (C)	793.015			8.234	H. I.—FS=Elev. 801.249—8.234. =793.015.
T. P. I (C)		9.340	802.355		—17.679
T. P. II (D)	801.560			0.795	+17.079 —00.600
T. P. II (D)		6.490	808.050		
B	799.400			8.650	
		+17.079		—17.679	

137. The above operation of finding the difference in elevation of two points is called *Differential Leveling*. A check on the work is to add all the B. S.'s together and all the F. S.'s together; take the smaller sum from the larger, and the result is the difference in elevation required between A and B, if plus (+) B is higher, if minus (—) B is lower than A. It will be observed that a back sight (see figure) on B. M. or turning point is always *added* to the elevation of that point to obtain the H. I.; the fore sight on any point is *subtracted*

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from the preceding H. I. to get the elevation at that point. The distance from the B. S. station to the level, should be about equal to the distance to the next turning point, in order to eliminate errors due to lack of adjustment of the instrument and to curvature of the earth. For even if the line of sight is inclined up or down, still two positions of the target at equal distance from the level will be at the same elevation. See 4th adjustment of the transit, par. 94, and figure 55, p. 103. In the same manner, errors of refraction which cause objects observed to appear too high are eliminated if observations are taken at equal distances from the instrument.

PROFILE LEVELING.

138. *Profile leveling* consists in finding the elevation of a number of points along the profile line A B, figure 79. The only difference of method from that described above for differential leveling is that there may be a number of foresights taken from any instrument station to points desired. The elevation of these points does not affect the record otherwise as will be seen by comparing the form below with that for differential leveling on the line A B. It will be seen that the levels are carried forward from one T. P. to another, exactly as in differential work. The distance from A to the *critical points,* par. 166, are measured with steel tape or chain and recorded as 1, 2, 3, 3+40 etc., meaning 100 feet, 200 feet, 300 feet, 340 feet from A.

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FORM OF RECORD FOR PROFILE (OR CROSS SECTION) LEVELING.

139 Figure 79.

Station Observed	Elevation	B S. +	H. I.	F. S. —	Remarks
B. M. A.	800	1.249	801.249		
1 (100 ft. from A)	793.749			7.500	801.249—7.50=793.749 H. I.—F. S.=Elevation
T. P. 1. (C)	793.015			8.234	801.249—8.234=793.015
T. P. 1. (C)		9.340	802.355		B. S.+Elev. T. P. (or B. M.)=H. I 9.340+793.015=802.355
2	793.055			9.3	
2+40	792.2			10.1	
T. P. 2 (D)	801.560			0.795	
T. P. 2 (D)		6.490	808.050		
B (4+20)	799.400			8.650	

TO PLOT THE PROFILE.

140. Select a sheet of profile paper or cross section paper, par. 196, with equally spaced horizontal and vertical lines, figure 82, and assume a

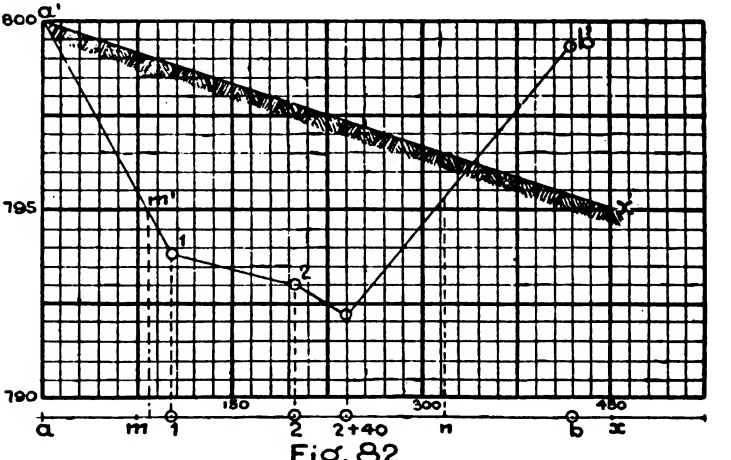

Fig. 82

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convenient scale which should be larger than the horizontal scale in order to exaggerate the elevations as compared with the horizontal distances and thus show clearly the various changes of slope. The vertical scale in the figure is assumed as 1 inch=5 feet; horizontal scale 1 inch=150 feet. The horizontal scale of a profile is usually the same as that of the map made of the area from which the profile is taken. Opposite *a* (zero of the horizontal scale) locate *a'* on the 800 foot line of the profile paper. Similarly, opposite 100 locate sta. 1 at 793.7; opposite 200, locate 2 at 793.0 and so on to the end as shown in the figure. The points at which 5 foot contours would cross *a b*, which is the horizontal projection of the profile on the map, are found by projecting down to the line *a b* the points at which the 795, etc., lines of the profile paper intersect the profile *a'*, 1, 2, 2+40, *b'*. For example, the 795 contour crosses the profile at *m'*. (see contour interpolation, par. 167)* If no profile or cross section paper is available the profile can be plotted on ordinary paper by drawing the vertical and horizontal coordinates of each station on the assumed horizontal and vertical scale.

If the profile has been determined for the purpose of locating a road, railroad, etc., a *Grade Line* of the required slope is plotted on the sheet as shown in the figure and the lineal cut or fill at any point as *m* is found by scaling off at that point the

*This is the basis of the method given, par. 167, for the interpolation of contours, except that in that work no profile is drawn in.

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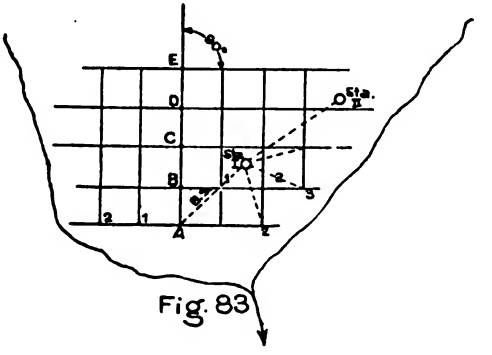
elevation of the profile and the elevation of the grade line then subtracting the smaller from the greater. The difference is the number of feet cut or fill. Elevation of grade=799.2—795 (elev. of m)=4.2 feet of fill.

CROSS SECTION LEVELING.

141. The record and method of leveling are the same as above whether the points whose elevations are sought are in one straight line or are in a number of lines. For instance suppose the ground area, figure 83, is to be Cross Sectioned; stakes are set at the corner of each square.



The leveling is carried on as shown in profile record, fore sights being taken from each instrument station to any points of the area on which the rod is visible from this station and are recorded as A R 1, B L 2 etc., meaning 100 feet to the right of A, 200 feet to the left of B, etc., looking from A to E. A rough sketch of the area should be made as a part of the notes. For example, the instrument is set up at sta. I, a B. S. is taken to A of

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which the elevation is known and a F. S. read on the critical points visible in the vicinity, as A R 2, B R 3, C R 3, etc.

To Range Out Lines Perpendicular to A E: lay off on the ground, lines at right angles to A E as described, par. 114, and range out and measure the lines to the edge of the area, driving stakes at critical points (see par. 166).

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CHAPTER VI.

PLANE TABLE SURVEYING

THE SELECTION OF THE SCALE OF A MAP OR SKETCH

142. Two conflicting conditions must be considered in choosing the scale on which a military topographical map is to be made.

1st, *the map must be large enough to show clearly the smallest details required.* Assuming that 1/20 in. is the smallest map distance that can be readily scaled in solving problems on such maps in the field, this distance must be made to represent the smallest ground distance necessarily shown. Suppose, for instance, that artillery ranges are to be shown to within 15 yards. Then 1/20″=15 yards; 1″=300 yards; 6″=1800 yards; or practically 6″=1 mile. This then would be a suitable scale for position and outpost sketches, and maps of reservations and small areas.

2nd. The next question to be considered is whether the map on the desirable scale is too large *for convenient handling.* A combined position sketch covering a division front of about 8 miles, and a depth of 2 miles would give a map 12″x18″—not inconveniently large for the purpose.

3rd. A third condition is whether the scale is of *suitable size for ready execution* in the field. In general, plane table work can be most satisfactorily

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executed on a scale of 6″=1 mile. Position and outpost sketches giving all details of military importance have also been found to be most readily executed at 6″=1 mile. If smaller scale maps of large areas are required they can be readily secured by reducing those mentioned above, see par. 210. *The relative accuracy of the instruments and methods used should* also be considered in map work. For example, it would be absurd to use a transit reading to minutes if distances were obtained by pacing, in which errors 1 in 100 are probable; because an error of one minute in angle causes an error of one foot in a course of about 700 feet; whereas the error of pacing might be 35 to 40 feet. In the same manner it would not be necessary to make a road sketch on a scale where 5 yards could be accurately plotted if, in the average length of courses, an error of rate of the horse might be as much as 20 yards.

The amount of detail desired on the map is an important consideration in military maps, and the larger the scale the greater the amount of detail that can be shown in such a form as to be readily comprehended by an inspection of the map. In tactical maps every small feature affording cover is of importance, hence a large scale is necessary for the representation of details; but strategical maps need only show general features such as main roads, mountains, etc., hence the scale may be very small.

143. Considerations similar to the above have

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led to the adoption of the following scales for military maps and sketches in the U. S. Army:

1st. Road sketches 3 inches=1 mile, with contours at 20 feet vertical interval (V. I.)

2nd. Position and outpost sketches, 6 inches=1 mile; 10 foot (V. I.)

3rd. Fortress and war game maps or those used in sieges, 12 inches=1 mile, 5 foot (V. I.)

This is called the *"Normal System"* of map scales, because any given M. D. (see par. 25), between contours represents the same slope on all the maps, see par. 27 (3).

THE EXECUTION OF A MILITARY SURVEY.

144. *The Plane Table and Stadia Survey.* The object of Part II of this book is to teach a beginner how to make a complete military topographical map covering an area of 1 to 20 square miles with the assistance of officers or enlisted men. Such a map may be made by a number of different methods among which are the transit and chain; the transit and stadia; and the plane table and stadia methods. The plane table and stadia method is most suitable for military surveying both because it gives the most faithful representation of the ground and also because the topographical training of the eye is by it best secured. This method consists of plotting in the field on the map sheet, the topographical details of the area. The various essential points on the ground are sighted through the telescope, lines are drawn along a ruler and the distances of the points from the instrument are

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read (see par. 117) on the stadia rod, and plotted at once on the lines.

145. *The Instruments Used in the Plane Table Survey*:

1. *Plane Table,* figure 49, p. 94.
2. *Stadia Rods,* figure 67, p. 117.
3. *Wye Level,* figure 73, p. 129, and *Level Rod,* figure 75.
4. 100 *foot steel Tape* figure 57; or 100 foot chain, figure 60.
5. *Eraser, note book, plotting points* (wax headed needles), *hatchet, stakes, marking chalk.*
6. *Stadia Computer,* figure 72, p. 127.

SURVEY PARTY.

146. *The Survey Party* should consist of a chief; an assistant; two rodmen; one or more axemen depending on the amount of underbrush in the area. In addition to the above, there will be required for survey parties, when in the field away from a garrison, a cook and a man to care for the animals of the party.

The Chief of the party is responsible for all parts of the work, has full charge of the party and assigns the members as he sees fit. The assistant should be prepared to relieve the chief of any part of the work. He should especially be able to read and reduce stadia readings rapidly and accurately. The two rodmen should have a good knowledge of ground forms so that they can select the necessary critical points with but slight direction from the instrument-men.

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METHOD OF MAKING PLANE TABLE SURVEY.

147. The steps in the work are:

1. *Triangulation.*
2. *Location of Details, including Contours.*
3. *Finishing map.*

TRIANGULATION.

148. In all classes of surveys, from the most extensive geodetic survey of thousands of square miles, down to a limited position sketch, the framework or skeleton of the survey is *the triangulation system,* figure 85. It consists of a series of triangles generally covering the area to be mapped, and giving points accurately located horizontally and vertically as starting and controlling points from which details of the area are plotted. The vertices of triangles can be located by intersection with great accuracy and thus the accumulation of large errors is avoided.

The triangulation system is determined by first

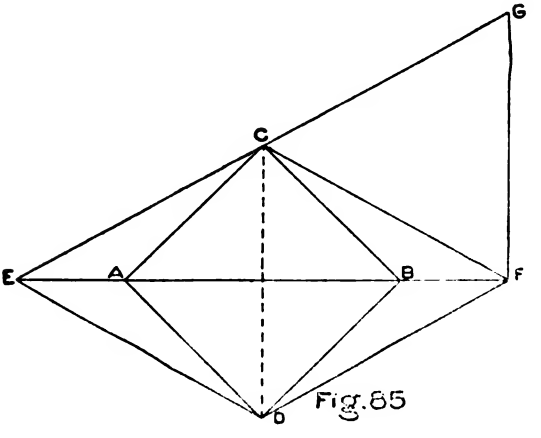

Fig. 85

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accurately locating and measuring a *Base Line* A B, figure 85, from whose ends a series of triangles as in the figure are extended.

THE BASE LINE.

149. A *Base Line* is selected as near the center of the area as practicable from which a good view is obtainable over the ground to be mapped. It should be on ground as level as possible and should be of sufficient length to give a series of triangles with angles greater than 30° and as nearly isoceles as possible. The Base Line should be measured with an accuracy proportioned to the size of the area to be surveyed and the requirements of the map; and the elevations of its two ends, accurately determined with wye level as described par. 135. In topographical surveys of military positions, reservations, camp sites and maneuver grounds with precise instruments, an accuracy of base line measurement of $\frac{1}{5000}$ is sufficient. An accuracy of $\frac{1}{5000}$ means that for every 5000 feet horizontal distance, the measured distance is most liable to be between 4999 and 5001 feet.

TO MEASURE A BASE LINE WITH AN ACCURACY OF $\frac{1}{5000}$

150. Two measurements are made with the 100 foot tape, one in each direction. For the required accuracy, the tape can be held sufficiently horizontal

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by hand. The pull should be as uniform for each tape length as can be estimated. The ends of the tape are marked with pins, and the direction is maintained by lining in (see par. 112). If the slope is too great for the full tape length to be held horizontal, on account of the height above the ground of the tape at the high end, half or quarter tape lengths must be used, figure 62, p. 113. A plumb line should be used on sloping ground to exactly mark the tape end, figure 62. On a uniform slope, the measurements may be made along the surface and converted into horizontal distances, figure 62, by the formula CB=D B cos a=corect horizontal distance. Or $CB=\sqrt{(DB)^2-(DC)^2}$ which DC is the difference in elevation between B and D.

The elevation of A is determined with Wye level, see par. 135, with reference to the nearest known B. M. of a government or reputable private survey. B is similarly determined with reference to A.

DETERMINING THE TRIANGLES.

151. Having measured the base line with the required accuracy, the triangulation system may be determined, either with a transit or plane table. For large areas necessitating geodetic methods the transit is generally used because of the errors liable to occur due to ununiform shrinkage and expansion of the plane table paper, and the desirability of calculating the exact direction of the lines with respect to the true meridian. But having given a drawing surface (paper, celluloid etc.) in which

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there is only a slight and uniform expansion or contraction, the plane table triangulation is sufficiently accurate, because the exact directions observed are obtained free from inaccuracies of angle reading and plotting. As long as the expansion or contraction is uniform in all directions no errors result.

152. For military topographical surveys, such as considered in this book, *the triangulation system* is *best extended with the plane table,* as follows:

Plot the base line A B* to the desired scale of the triangulation on a sheet of *Unchangeable Drawing Board*† which has been seasoned by several weeks of exposure to the air. This board is specially made so that it will not contract or expand due to atmospheric changes. Draw on the board two accurate graphical scales of yards along two perpendicular edges of the board, and test the accuracy of these scales at the time of plotting each side of the triangles to see if there has been any change of the dimensions of the sheet. The base line should be so located on the sheet that the entire area to be mapped will be included by it.

Intersection: Set up and level the plane table over station A (figure 86, 1st position) orient (see

*Throughout this book when a ground area and the corresponding map are discussed the small letters *a*, *b*, *c*, etc., and Roman numerals 1, 2, 3, etc., are used to represent map locations; Capitals, A, B, C, etc. and Arabic numerals I, II, III, etc. are used to represent the corresponding positions on the ground.

†Sold by Keuffel & Esser, New York.

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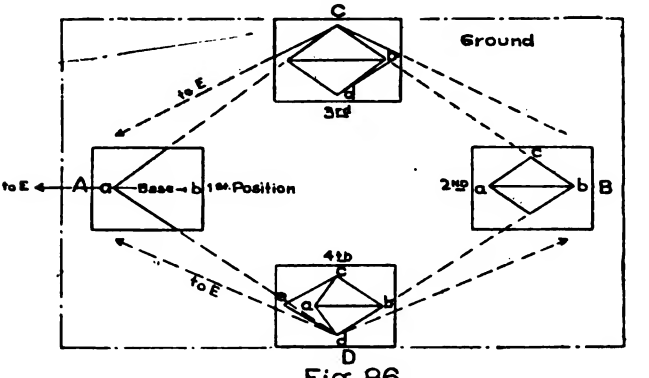

Fig. 86

par. 34) the table by placing the alidade ruler along *a b* and rotating the plane table horizontally until a rod on B is accurately bisected by the cross-wires of the telescope. The point *a* on the plane table sheet is placed exactly over A by the use of the plumbing arm N, figure 49, p. 94.

The sheet having been thus oriented, direct the telescope toward triangulation stations, such as C and D, figure 86, which, with A and B, will make triangles, no angle of which will be less than 30° nor greater than 120°, in order to insure accurate intersections. Draw indefinite lines toward C and D. Next move the instrument to B (figure 86, 2nd position). Set up level and orient as at A. Sight C and D and draw lines intersecting those drawn from A at *c* and *d*, which are the plotted positions of C and D. The points thus located from A and B may be similarly used as new base ends for locating new triangulation stations such as E, F, etc. In this manner the entire area to be mapped is covered with points whose horizontal positions are plotted

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on the map sheet and whose elevations are recorded as the basis for the work of filling in details.

Vertical angles are read from A by sighting on an elastic band fixed at the height of the telescope axis above A, on the stadia rod held on C and D (see *c* fig. 67, p. 117), to determine the elevation of C and D. This method of finding the differences of elevation is described in par. 120. These elevations should not be in error more than .5 foot per mile from A to the point under consideration in the triangulation. The elevation found should be corrected for curvature of the earth and refraction by the air, as follows: add to each at the rate of 8 inches times the square of the length of sight in miles decreased by 1/7 to allow for refraction. For example, suppose a sight is 2 miles long. $8 \times (2)^2 = 32''$. $32 - (32 \times 1/7) = 32 - 4.5 = 27.5$ inches =the correction to be added.

TO PLACE THE TRUE AND MAGNETIC MERIDIANS ON THE PLANE TABLE SHEET.

153. Draw on an edge of the oriented sheet the magnetic meridian parallel to the west or east side of the compass box in position with the north end of the needle reading zero.

(1) Lay off with a protractor a line making with the magnetic meridian an angle equal to the declination but in *an opposite angular direction* (that is west if the declination is east and vice versa). The line thus located is the true meridian.

(2) Or, rotate the compass box in a direction *opposite to the declination* until the needle reads the

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exact angle of the declination. Draw a line along the east or west side of the box, and this is the true meridian. (To determine the position of the true meridian see par. 64)

FILLING IN DETAILS.

154. This consists in determining the horizontal distances, the elevations, and the relative directions of sufficient critical points (see par. 166) to enable the topographer to accurately represent the area by contours (see par. 22) and conventional signs (see fig. 18, p. 42).

Locations for filling in details are made (1) by *Resection,* (2) by *Intersection,* (3) by *Traverse.*

RESECTION LOCATIONS

155. *To locate a point by resection,* the plane table is set up *at the desired point* on the ground whose map position is unknown, and sights are taken to two or more points on the ground whose map positions are plotted.

1st method of Resection: Having given a direction line and a plotted point outside of that line, to determine the map position of any point lying in the direction line.

Set up and level (pars. 79 and 80) the plane table at the desired point, as C, figure 87, then orient by placing the alidade along *a c* and rotating the table horizontally until a rod at A is accurately sighted. Clamp the table in this position. Pivot the alidade about a plotting point (needle) at *b,* sighting B. Draw a line from *b* back toward the observer until

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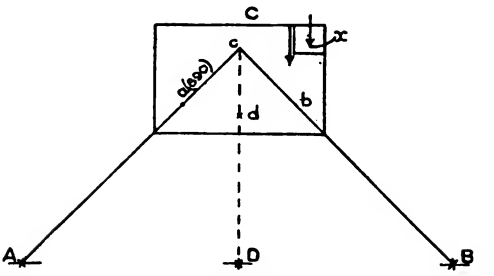

Fig. 87

it crosses the line *a c*. This point of intersection is the map position of the plane table's ground position C. This method of resection is of great value in extending a secondary system of triangulation (one with sides from $\frac{1}{2}$ to 2 miles) or for filling in detail in a plane table survey and in all forms of rapid area sketching. For example, the topographer at one of the plotted stations as *a, b, c,* etc., observes that it will be desirable to set up near a certain ridge, he draws an indefinite line toward a tree, telegraph pole, or other well marked spot, in the desired direction. At any later time he can set up at any point in this line and determine his position as above, in order to plot with stadia readings the details in the vicinity.

2nd method of Resection: Having given two plotted points *a* and *b* to determine a third point *c*, orienting with the compass.

Set up, level and orient the table at C, by placing the N S line of the compass box along the magnetic meridian on the sheet as at *x*, figure 87, and then rotate the table until the north end of the needle reads zero. Clamp the table in this position.

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Pivot the alidade on *a*, at the same time sighting A, and draw a line along the ruler toward the observer. Similarly pivot the alidade on *b*, sighting B and drawing a line back along the ruler until it cuts the line from *a*. The point of intersection is the required point *c*. This method is especially valuable in determining plane-table stations for locating details around any point from which a good view is obtainable. Any slight error in the location of the point due to local attraction (see par. 62) of the needle is of no consequence because it applies only to this one location and does not affect other determinations with an accumulative error.

Having located the horizontal position of the unknown point by either of the above methods, the vertical angle is read from C to a known station, as A, figure 87, to determine the elevation of C. (See par. 120, determining elevations by vertical angles).

3rd. Method of Resection: Having given three plotted points *a*, *b* and *c* whose ground positions are all visible from the unknown point D.

Set up and level the plane table at the unknown point D, figure 87, and attach a sheet of tracing paper on the table. Assume the location of the unknown point *d* on the tracing paper, from D sight toward the three known points A, B and C, drawing lines toward each from *d*. Now loosen the tracing paper and so shift it as to bring the line *da* over *a* of the map, the line *d b* over *b* of the map, the line *d c* over *c* of the map. When this is done, prick through with a needle the position of *d* into the map

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and the unknown point is thus correctly located. The board is now oriented by placing the alidade along one of the lines as *d a* and rotating the board until A is accurately sighted through the telescope.*

4th method of Resection: Having given two plotted points on the map *a* and *b* (figure 88, 3rd position of plane table) both of which are visible on the ground, to locate the map position *d* of an unknown point D, using an auxiliary point, as C, whose map position and distance from D are unknown. Set up and roughly orient at C (figure 88, 1st position) from which A, B and D are visible. Attach a sheet of tracing paper on the table and assume a point on it to represent C at *c'*. Draw

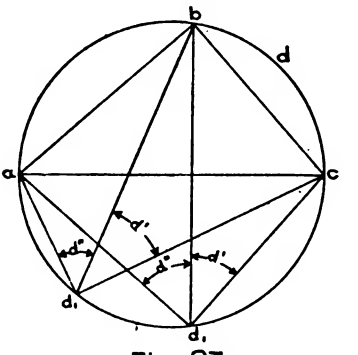

Fig. 87.a

*Care should be taken in choosing the known points, A, B, and C on which to sight, that the circumference of the circle containing them does not also contain *d*. For if this condition exists then the location of *d* is indeterminate since at any point of the circumference, figure 87 (a), the angles *d'* and *d''* are constant, being measured by arcs *bc* and *ab* respectively. To be on the safe side, the unknown point should lie where practicable outside the angle included by the three points as at *d*.

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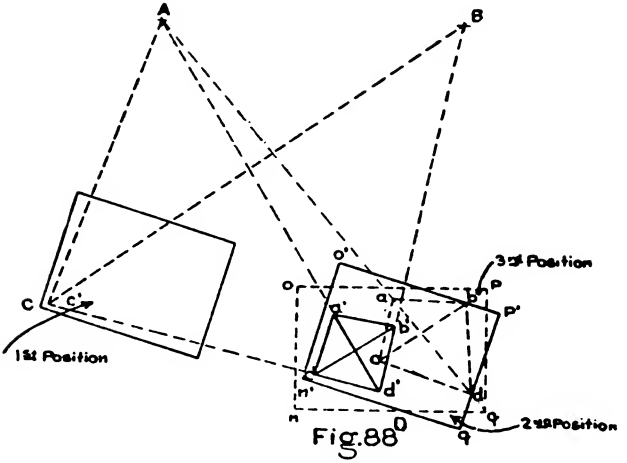

Fig. 88

rays toward A, B and D. Move to D, assume the point d' on the tracing paper in the line c' d' (2nd position) and set up the plane table (n' o' p' q'), orienting by a back sight on the line c' d'. Draw rays from d' toward A and B. The intersection at a' and b', of these rays, with those previously drawn from c', determines a quadrilateral a' b' c' d', of which the scale was assumed by assuming the length c' d', exactly similar to the quadrilateral A B C D on the ground. Now shift the tracing paper and fasten it with b' lying over b on the map sheet, and the line a' b' on the line a b (3rd position of table). Revolve the table until the line $b'd'$ points toward B. This orients the table in the position n o p q. Remove the tracing paper and pivot the alidade on b, sighting B, and then on a, sighting A; draw the latter ray back until it cuts the line b d in d (that is, resecting on B and A. This locates the required point d on the map. C may be found by drawing

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$a\ c$ on the map parallel to $a'\ c'$ on the tracing paper (b' on b and a' on the line $a\ b$), and extending the last position of $c'\ b'$ until they intersect at c. This method of resection is valuable for extending a triangulation in which the topographer would not wish to depend on the needle for orientation. The auxiliary point C may be selected as close to D as the securing of good intersection angles will allow.

LOCATIONS BY INTERSECTION.

156. It will be necessary to locate points by intersection, when the point, at which information is desired on the map, can be seen from located stations but cannot be used as an instrument station. As for instance, the juncture of two streams whose horizontal positions and elevations are important, but from which the very limited view possible prevents setting up there. These points will be located by intersection as described par. 152, except that the same degree of care will not be necessary and the intersection angles may vary from 30 to 120 degrees. The elevation of such a point would be obtained by reading the vertical angle and reducing the stadia reading as described par. 120. One of the greatest advantages of the plane-table over the transit is that the instrument, due to its capacity for resection and intersection, need not be set up at points barren of detail, as is required in the transit traverse simply to move from one desired station to another. As soon as two or three points are located on the sheet the plane table can be set up at any desired point by resection, and the work of plotting be begun.

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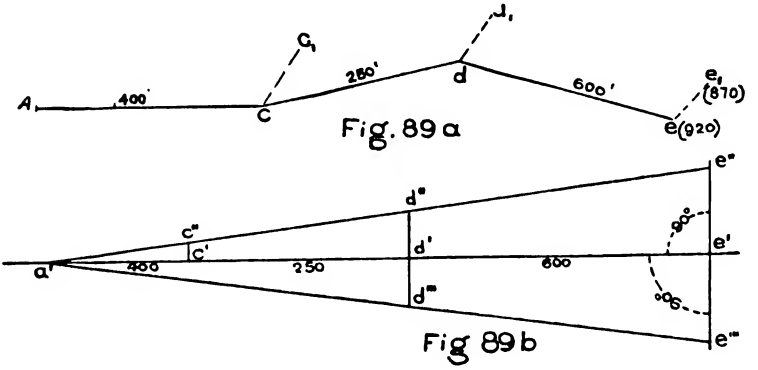
LOCATIONS BY TRAVERSE.

157. In the area to be mapped there will usually be critical points, par. 166 which are invisible from any known station such as those low down in valleys or in woods, etc. In such cases a traverse is run with the plane table and stadia, as follows: Set up and level the plane table at the known station A, figure 89 (a) and orient by a back sight to the last known station, par. 152. The front rodman meas-



ures the H. I. above A, places the elastic cord at this point on the stadia rod (par. 120, foot note) and holds the rod vertically on a well driven stake at C, from 400 to 800 feet in the general direction desired for the traverse. The observer sights the corner of the rod directly over a tack on stake C. He then sets the lower stadia wire on an even hundred division of the rod [or at the top of a $(c+f)$ division if these are on the rod] reads and calls out to the recorder the number of divisions between this and the upper stadia wire. The observer then elevates or lowers the telscope about its horizontal axis,

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until the middle horizontal wire bisects the elastic cord, then reads on the vertical circle the angle of slope and calls it out to the recorder. The observer then draws a line along the alidade ruler toward C and marks the distance *a c*, figure 89 (a), to scale, as given by the recorder. He then writes at *c* its proper elevation as given him by the recorder, and interpolates contour points on *a c* (see par. 167). As soon as the observer calls out the stadia reading and vertical angles the recorder writes them down in the note book (see par. 158, form of notes), and immediately reads from the stadia computer (see par. 123) the correct horizontal distance *a c*. He similarly reads and records the difference of elevation between *a* and *c*, and adds (or subtracts) this difference to the known elevation of *a*, according as the vertical angle to *c* was positive (+) or negative (—). The observations are plotted at once but in order to keep a record of them in case a later verification is necessary, the recorder enters them in the note book.

FORM FOR PLANE TABLE AND STADIA NOTES.

NOTES	V. A.	Stadia	Hor. Dist.	Diff. Elev.	Elev.	Remarks
Point Observed		At Stat	ion A.			Elevation A=830
C	4° 45′	5 47	542 ft.	+45′	875	

158. Having located all details in the vicinity of C, the traverse is similarly carried forward to other stations as D, etc., until another known point is reached. Suppose E is such a known point plot-

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ted in e_1 (870). From D the observer sights E and locates *e* as prescribed for locating C above.

ERRORS AND THEIR ADJUSTMENT.

159. The difference in this position of e, and its position as formerly located by triangulation (e_1) is the accumulated error of the traverse. This error for traverses of 1 to 2 miles would usually be less than 20 feet. An error of 20 feet on the scale of 6″= 1 mile is $\frac{1}{44}$ inch and negligible in such filling in work. If the error is large enough to represent as much as $\frac{1}{8}$ inch it is distributed among the last few courses as follows, figure 89 (b): A line *a′ e′* is laid off equal in length to *a c*+*c d*+*d e*. At *e′*, a line *e′ e″* is drawn perpendicular to *a′ e′* and equal in length to the error *e* e_1. *e″* and *a′* are joined by a straight line, and *d′ d″*, *c′ c″* are drawn parallel to *e′ e″*. *d′ d″* and *c′ c″* are the amounts to scale of the corrections respectively at *d* and *c*. At *c* and *d* draw lines parallel to *e* e_1, and equal respectively to *c′ c″* and *d′ d″*, thus locating the adjusted positions of the stations *c*, *d*, etc., at c_1, d_1, etc. As will be observed, *the adjustment at any station is proportional to the distance of that station from the first station a*, and *assumes that the error was accumulated gradually throughout the traverse.*

If the elevation of *e* as determined by the traverse is not equal to that of e_1, the elevation of the traverse station may be adjusted in exactly the same way. In this case *e′ e‴* would be taken equal to the error of elevation on any convenient scale.

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Suppose the elevation of e is (920), of e_1 is (870). Then lay off $e'\ e'''$=50 feet. Assume a scale of $\frac{1}{2}$ inch=50 ft. Then $e'\ e'''$=$\frac{1}{2}$ inch. $d'\ d'''$ =.28 inch =.28×100 ft.=28.00 feet. If such an adjustment is necessary, the stations of the traverse to be adjusted are traced on tracing paper, the adjustments made thereon and pricked through on the map sheet.

TO LOCATE SIDE SHOTS.

160. From any located station whether triangulation, resection or traverse, the details* around the plane table station to about 800 feet distant, if the ground is visible, are located by what are known as *side shots*. These are independent locations used only for securing local detail, but not used as instrument stations. They will usually be determined by sights on the stadia rod held on the critical points, but may in some cases be determined by chaining, pacing, etc., as for width of streets, size of prominent buildings, etc.

To locate details with the stadia, the rodmen are directed to critical points, each of which is located as prescribed for the location of C under traversing par. 157, except that no stakes are driven and the same care as for a traverse station is not required. The observer and an assistant (recorder) should, with practice, keep two or three rodmen busy, and still be able to keep up with the elevation of each point located and the important contour interpola-

*For a statement of the details which should be located on a military map see par. 164.

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tions (see interpolation par. 167). If the rodmen are mounted the work will be much facilitated.

161. *Radiation Method*: Two rodmen may often be used to advantage as follows, figure 90: With

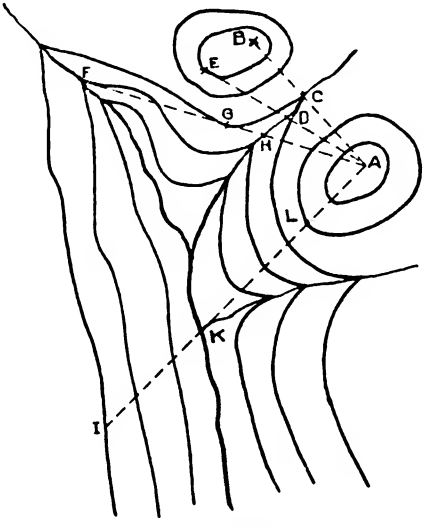

Fig. 90

the plane table in position at A, the observer directs rodman number 1 to the critical point B, as far from A as practicable, and draws a line toward B and reads the stadia, plotting the point at *b* and writing there its elevation. Rodman number 2, in the meantime, should have moved to the next critical point toward A from B as at C. He is lined in on A by rodman No. 1 and the horizontal distance and elevation of C are at once determined and recorded as above for B. Rodman No. 1 meantime should have moved to the next critical point toward A from C, or if there are no more such points in

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this line he moves over to a point in another line as at D from where the two rodmen move by alternate steps away from A toward the outer edge of the area. This system economizes the time of the observer in that he does not have a new direction to determine and a new ray to draw in for every critical point desired, so that he is able to keep up his plotting and contour interpolations as the work proceeds. The distance apart of the various radiating lines is to be determined by the number of critical points necessary at their ends farthest from A. Each critical point from an instrument station should have a serial number which should be recorded in the notes as cp_1 cp_2 and on the sheets as 1, 2, 3, 4, 5, etc., so that any plotting can be subsequently checked up. This systematic method of choosing critical points prevents the rodmen from failing to set the rod on all desired points.

162. *The recorder* assists the observer by recording the notes and reading from a Cox stadia computer, fig. 72, p. 127, the correct horizontal distance and difference of elevation corresponding to each given stadia reading and angle of slope. He also finds the correct total elevation of each critical point, by adding or subtracting the difference of elevation, and calls it off to the observer who records it in parenthesis at the plotted point. The observer should also be able to interpolate contours (see par. 167) between the various locations without delaying the rodmen after they arrive at any critical point.

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PLANE TABLE AND STADIA SURVEY, WITH TRANSIT USED TO READ STADIA.

163. The transit may be used for reading the stadia and vertical angle when the plane table alidade has no telescope, figure 48, p. 92, by having the transit and plane table set up side by side at each instrument station and about 4 feet apart to allow the observer to pass between them, figure 91. The observer sights each rod position

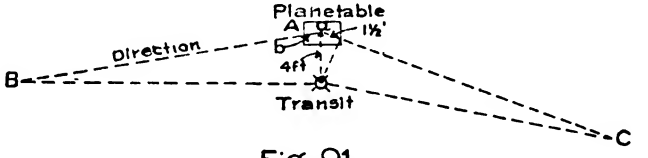

Fig. 91

through the sighting slits, draws the radiating line, and while he is doing this the recorder is reading the stadia and vertical angle on the rod. The recorder then reads from the computer, par. 123, the true distance and elevation of the point sighted to the observer who plots them as in the method first described, for plane-table with telescope. For example, suppose the observer at A (880) figure 90, rodman No. 1 at B. The observer sights the rod and draws line *a b* on the sheet. The recorder reads "stadia 425, vertical angle+6°30′." He sets zero of the stadia computer, at 425 and opposite 6°30′ on the distance scale finds 420 to which he adds 1½ feet allowance (see figure 91), calls off 411½ to the observer; and finds opposite 6°30′ on the elevation scale 47.5 feet which he adds to 880 and calls out "elevation 927.5 feet." It is evident that the

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work can be done much more rapidly by this method than with the plane table alone, because of the more equal division of the labor between observer and recorder. The observer can devote more time and study to the ground and its contouring, and the assistant to estimating distances, slopes and elevations. This method also has the advantage that stadia readings and vertical angles are more rapidly and accurately read with a transit than with a plane table alidade because of the difficulty of maintaining the large drawing surface of the plane table in sufficiently exact level to give accurate vertical angles. The telescope alidade is heavy and awkward to use and carry from one station to another. In taking readings with it the observer is very liable to lean down on the plane table so that his breast rests against the board. If this occurs his breathing causes the board to move up and down deranging the reading on the rod. Therefore, always use the transit and plane table where a transit is available. Figure 48, p. 92, shows a good light plane table for this work. In taking the stadia reading an allowance must be made by the recorder for the difference in distance from the transit and from the plane table to the point sighted, but this can be estimated within one-half foot which is close enough for all detail locations that do not enter later work accumulating the error, or for short traverses. The plane-table stations themselves are to be located by intersection, traverse or resection.

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THE DETERMINATION AND PLOTTING OF CONTOURS AND MILITARY DETAILS.

164. For the meaning of contours and the contour method of representing elevations, slopes and ground forms see Part 1, par. 22. By *Military Details* is meant all works of man and various kinds of growths of military importance: such as furnish cover or obstacles; points or objects of attack or defense; means of communication and supply. These features are represented by conventional signs (see fig. 18, p. 42 and figures 144 and 145, pps. 259, 260). In showing features by conventional signs, the military importance of the objects to be represented should be constantly kept in mind. The shape and character of woods, the direction and character of roads and railroads, and the important towns on them; the extent of all kinds of growth affording shelter or forming obstacles should be shown. Ponds, lakes and streams are always of importance. It will frequently save time and tend to clearness to write simply the character of growth in a given enclosure, with a border of the conventional signs showing the shape and size of the tract covered. To fill up a map with a multitude of grass symbols may be avoided by leaving all parts blank in which the growth affords no cover and forms no obstacle.

165. *Contours* are determined by locating a series of critical points (see par. 166), over an area to be mapped, each of which gives the greatest possible amount of information of the shape of the ground. Military Details are similarly obtained by

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taking the critical points so as to obtain the most correct information of the character and location of the object to be represented.

166. *A Critical Point* is one at which there is an abrupt change of general slope, as at H, B, C, in the profile, figure 93 (a); or an abrupt change of

Fig. 93a

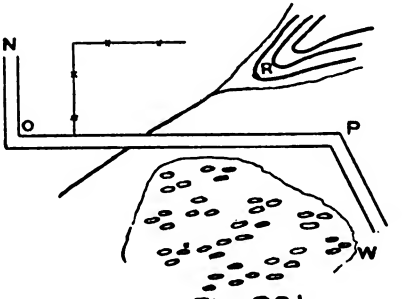

Fig. 93b

horizontal direction as at P on the road, figure 93 (b), or at the corner of the woods at W or at the stream junction at the foot of the water shed at R. The critical points most valuable for contour location, are at the top of a hill, the junction of streams, the head of a ravine, and the foot of a spur or water shed.

INTERPOLATION OF CONTOURS.

167. Between any two determined critical points connected by a uniform slope, contours are interpolated as follows, figure 94:

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Suppose *a b* and *c* are three points located on the map sheet and it is required to interpolate contours between *a* and *b* and between *b* and *c*: Lay a sheet of cross-section paper, as in the figure, along *a* (elev. 862) and *b* (895). [In the figure, the bottom cross-section line (860) is placed a short distance from the line *a b* for clearness]. Assume the bottom line of the cross-section sheet to be elevation 860 and that each heavy horizontal line represents 10 feet as shown on the scale of elevations. Mark opposite *b* the point *b'* at the elevation of *b* on the map (895). Lay a ruler on *a'* and *b'* as shown in the figure and drop perpendiculars down on the line *a b* from the points where the ruler crosses the 870, 880 and 890 lines on the cross-section sheet. The points in which these perpendiculars meet the line *a b* are contour points. These points are in practice estimated by eye with the assistance of the closely spaced vertical lines of the cross-section sheet perpendicular to *a b* without drawing the perpendiculars such as *m' m*. No line is drawn from *a'* to *b'*, but it is marked by the ruler during the interpolation, so that the cross-section sheet can be used any number of times. The cross-section sheet and ruler must be kept fixed in position by weights or by hand until the interpolation between these two points is finished. The line marked by the ruler is the profile of the ground from *a* to *b*, revolved down into the plane of the paper about *ab* as an axis. This profile will be shown if the drawing figure 94 is creased on the 862 line so that the

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cross-section sheet stands perpendicular to the map represented in the area *a b c*. The contour points on *b c* are similarly determined at the points shown, by moving the sheet of cross-section paper so that it lies along *b c*. Here the lowest horizontal of the cross-section sheet would be assumed as 830 to be of less elevation than the lower of the two points

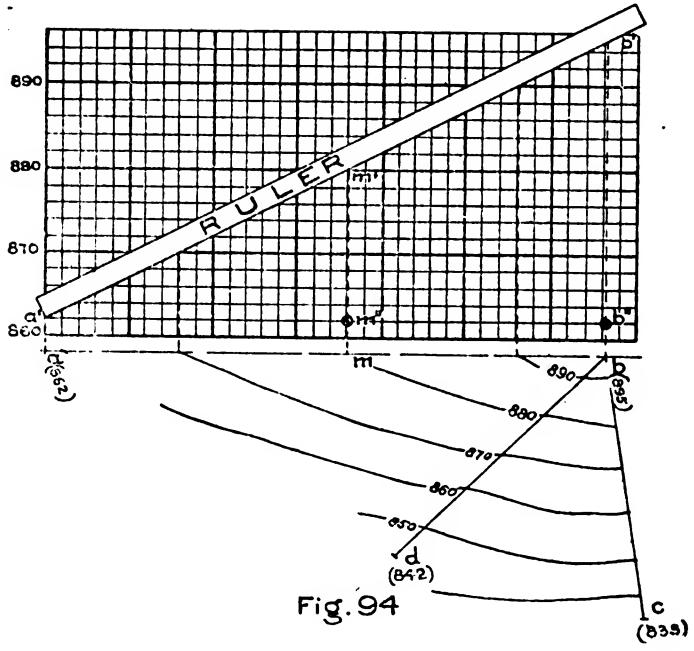

Fig. 94

b and *c*. The number of cross-section vertical divisions representing 10 feet is assumed at pleasure for each location depending on the difference in elevation between the two points such as *a* and *b*, between which interpolations are being made. The elevation of the lower of the two points is assumed on the cross-section sheet so that the heavy lines

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will represent contour elevations. The contour points on *b d* are likewise determined and then the contours along this hillside are drawn in so as to conform to the slope of the ground as it lies before the observer.

168. *The use of cross-section paper* for interpolating contours furnishes a rapid graphical solution which gives the same results as if the profile (see par. 140) of *a b, b c* etc., were each constructed as in figure 82, p. 140, the contours located on it and then projected down on *a b* etc. The contours could be located by arithmetical proportion but this method is much slower especially where decimal parts of feet are considered.

To locate by proportion the point m where the 880 contour crosses a b: Suppose the base *a′ b″* of triangle a′ b″ b′=2.89 inches, and is at elevation 862. Then we have the proportion *b″ b′ :m″ m′* : : *a′ b″ :a′ m″*. That is 33:18 : : 2.89 : *a′ m″*. Whence $\frac{33}{18}=\frac{2.89}{a'm''}$, or am$=\frac{18\times 2.89}{33}=1.58$ in. from *a*.

Care must be used never to interpolate contours between two points lying on opposite sides of a hill top as M and N in the profile, figure 93 (a), p. 169, or on opposite sides of a stream line as N and E. In these cases the interpolations should be made between H and B, between B and C, etc. When drawing in contours in the field on the plane table sheet, after locating the contour points on any line, the observer would, when necessary, vary the

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spacing as required by the slope of the ground on the area between the lines *ab, bd* and *bc,* figure 94; if it is concave they would be closer together near the top than near the bottom and vice versa for convex slopes (see plate 3, p. 23). This allows the use of fewer critical points than if every slight variation of slope is used as a point to be observed, and much time is saved while the result is a true representation of the ground.

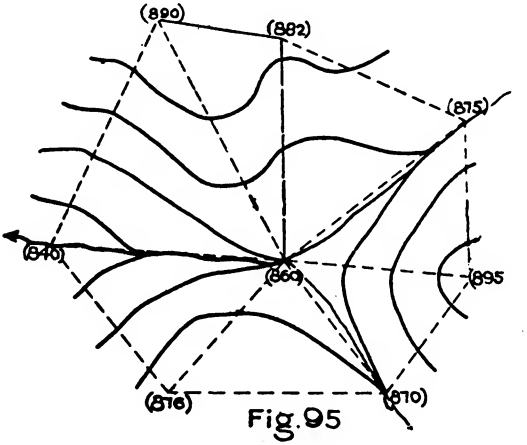

Fig. 95

169. Figure 95 shows the critical points observed in an area to be mapped; the broken lines show the rays along which interpolations are made at the points marked; the full lines show the contours as actually drawn in by the observer who constantly has the ground in view while doing the work. It will be observed that the lines on which interpolations are made divide the area into a series of triangles and this should in general be the case, each one of the triangles being so chosen that it may be as-

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sumed as a plane surface for the work of interpolation. In selecting critical points the scale of the map should always be kept in view, and only as many points be chosen as are necessary. For instance, if the scale is 6″=1 mile, 100 feet is represented by approximately .1 of an inch. It would be obviously unnecessary to take observations to show irregularities in the contour of 15 or 20 feet horizontally. One carefully selected critical point is better than half a dozen selected at random.

170. *The topographer's eye must be constantly trained* to appreciate slopes and ground forms and to comprehend the map distance of a given ground distance so that he can gradually dispense with more and more critical points and yet put in accurately the intervening contours and ground features. This method of surveying with plane table and transit is rapid and accurate, and its use is urged for all small area military surveys. It gives an excellent training to the eye in appreciating the possibilities of ground in all military operations.

AIDS TO ACCURACY.

171. *Well sharpened 6H pencils* should be used and fine lines should be drawn for location work.

The pencil should be held exactly vertical and the point close to the ruler.

Excellent *plotting points* may be made of medium sized needles with sealing wax heads. The points pricked for stations or critical points should be very minute.

One or more *check sights* should be taken, from

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every station occupied, on triangulation stations where visible, as a verification of the orientation of the table.

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CHAPTER VII.

TRANSIT AND STADIA SURVEY.

172. The transit may be used in making a military topographical survey instead of the plane-table, the essential difference being that the observations taken with the transit are recorded in a note book (see par. 177) and these notes, with rough sketches as a guide in plotting, are subsequently plotted indoors. It is therefore not possible to secure by this method the topographical training or the accuracy of representation of the ground forms and features possible with the plane table.

173. The field work of the transit and stadia survey is executed with the following instruments:

1. *Transit,* figure 42, p. 86, and par. 71.
2. *Stadia Rods,* figure 67 and par. 117.
3. *Wye Level,* figure 73, p. 129; Level Rods. figure 75 and par. 134.
4. *100 foot steel tape,* figure 57, or chain, figure 60, and par. 107.
5. *Note Book,* see par. 177.
6. *Hatchet, stakes, marking chalk.*

Survey Party, see par. 146.

TRAVERSE WITH TRANSIT AND STADIA.

174. Having established triangulation stations, as under the plane table, par. 148, the detail is filled in by running traverses with transit and stadia over

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the area in a series of loops, each of which should begin and end at a triangulation station. The following steps are taken in traversing:

1. *Set up, level (par. 72) and orient the transit at a point of the triangulation the starting point of the traverse (as A, figure 96); and take a sight on the nearest B. M. whose elevation is known.*
2. *Take side shots for detail around A.*
3. *Locate a forward station in the desired direction, as* I, *and read the azimuth, vertical angle and stadia.*
4. *Move the transit to station* I, *set up, level and orient by a back sight on a rod held on A.*
5. *Read vertical angle and stadia on A, as a check on the forward readings.*
6. *Take side shots for detail in the vicinity of* I.
7. *Traverse to* II, III, IV, *etc., until* B *is reached, as prescribed for traverse to* I.

To Orient the Transit: At the first station, A, to orient the transit in the meridian, set the zero of the vernier (A, fig. 42, p. 86) opposite the zero of the horizontal limb (main scale) and clamping the two plates together, by E figure 42, loosen the lower clamp C, and revolve the clamped limb and alidade* horizontally until the north point of the magnetic needle points at the north zero of the compass circle. Clamp the lower limb C and secure accurate zero reading of the needle with the tangent screw D. Release the upper clamp E.

*The alidade is all that part of the instrument which carries the line of sight. The upper plate forms a part of the alidade.

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The horizontal scale is now in a fixed position (oriented) with the index of vernier A *reading zero when the line of collimation lies in the meridian.* The vernier moving with the telescope marks on the limb the angle which any line sighted makes with the meridian. At all subsequent stations where the transit is oriented, the horizontal scale (limb) is parallel to its present position.

175. *To read on B. M.*: The rodman now places an elastic cord (see par. 120) on the rod at the H. I. above A. The observer sights the edge of the rod on B. M., figure 96, clamps the upper plate (by clamp E, fig. 42), reads the intercept between the stadia-wires, and, elevating the telescope about its horizontal axis Z until the cord is bisected by the middle horizontal wire, clamps (with N) the telescope. He then reads the azimuth on vernier A, and the vertical angle on vernier L, to the recorder, who records them in the proper column in the note book (see par. 177).

176. *Side Shots for Detail* (see par. 160): A rodman places a stadia rod on C. P. I, C. P. II, etc., which are located as prescribed for locating the B. M. and the record is made as shown in the notes. In these sights it will usually be sufficiently accurate to read the vertical and horizontal angles to the nearest 10′ and the stadia to the nearest 5 feet. A rough sketch of the ground to be mapped should accompany each sheet of the note book on the right hand page, left blank for this purpose. In order to sketch forward as the traverse progresses, *the notes may be conveniently kept from the bottom of each sheet to its top.*

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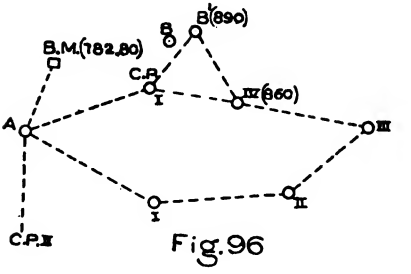

Fig. 96

TABLE OF TRANSIT AND STADIA NOTES.

177. (Figure 96)

Topographical Survey at———with Transit and Stadia. Azimuths from Magnetic Meridian, Magnetic Declination 8° 23′E.

Chief of Party—John Jones.
Assistant—Henry Smith.
Rodmen—George Price, Wm. Sievert.

September 30, 1909.

Point Observed	Azimuth	Check Bearing	Vertical Angle	Stadia	Horiz. Dist.	Diff. Elev.	Elev.	Remarks
	At Station A 800 H. I.=4.5 (Measured on Stadia Rod)							
B. M.	10° 10′	N10°E	—3°20′	125′*	125′	—7.2	792.80	
C. P. I.	70° 00′	N70°E	+8°00′	200′	...	.....	.....	
C. P. II.	175° 10′	S5°E	—7°35′	170′	...	.....	.....	
I	130° 23′	S49°30′E	+10°	600′	581′	+102.6	902.6	
	At Station I Elevation 902.6 feet H. I.=5.60							
A	310° 23′	N49°30′W	—6°19′	602′	.....			
II	89° 14′	N89°15′E	0°00′	300′	300′	00		
III	At Station II. Elevation———H. I.=4.90							
	269° 14′	S89°15′W	0°00′	300′	300′	00		
	69° 00	N69°E	+9°00′	690′	...			
I	At Station III. Elevation———H. I.=5.00							

*For angles smaller than 5°, no correction of the horizontal distance is made except on main traverse stations. Let the student reduce the uncompleted parts of the above set of notes.

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178. *To Locate Station* I: The front rodman places the front corner of the stadia rod on the tack in the top of the stake driven to mark station I.* The Observer accurately bisects the corner of the rod directly over the tack and as near it as possible and clamps the alidade with clamp E, figure 42; reads the stadia to the recorder, then elevating the telescope bisects the elastic cord at H. I. on the rod, before removing his eye from the telescope. He then reads the azimuth (see par. 69) on Vernier A, the check bearing on the compass; and then the vertical angle on the vernier L to the recorder who enters them in the notes.

179. *To Move to a New Station*: The lower clamp (C) is loosened and the telescope loosened (at N) to prevent strains on screw threads from accidental blows. The needle stop, *d*, figure 47, p. 89, is screwed down to take the needle off the pivot. The transit is then carried to station I, set up, leveled and the needle stop released.

180. *To Orient by a Back Sight*: The transit is oriented by setting vernier A (fig. 42, p. 86) to read an angle differing from the forward azimuth, A to I by 180°. That is, 180° is added to the forward azimuth unless this sum is greater than 360°, in which case 180° is subtracted from the forward

*The error arising, due to failure to place the plumb bob of the transit or plane-table exactly over the tack marking the station, increases as the distance to the next station observed is decreased. At one mile an error of 1 inch in position of the plumb bob causes an error of about 3 seconds of arc; but at 100 feet the error would be about 3 minutes. Keep in view that 1° at 57.3 feet=1 foot (see par. 25).

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azimuth. The two plates are clamped together by means of E fig. 42, and the rod on station A is then sighted; the lower clamp, C, is tightened and accurate bisection secured with the tangent screw, D. The stadia and vertical angle from I to A are then read as a check on the forward readings. If the two vertical angles are different in numerical value (indicating an index error of the vertical limb, see par. 98) one-half their arithmetical sum is the correct slope between the stations. The traverse is now continued in the same manner until B is reached.

CHECKS ON ACCURACY OF READINGS ON A TRANSIT:

181. *Be sure the proper set of graduations is read, i. e.,* inner or outer, figure 45, p. 87; *that the vernier is read in the same direction as the limb; that the correct vernier is read* (vernier A); *that angles such as 28° for 32°, 49½° for 50½° are not read; that the half degrees on the limb be added when necessary to the vernier reading, as 50°50′, instead of the erroneous reading 50°20′. The north point of the needle should always be read at each sight as a check on the azimuth read on the vernier, to prevent large errors of a degree or more. Remember that you read on the limb from zero of the limb up to index (zero) of the vernier, and then on the vernier from its zero up to coincidence,* see par. 58. *Estimate the fractional part of the division of the limb to be read with the vernier,* as this shows at about which vernier line to look for coincidence. If no division line of the vernier exactly coincides

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with one of the limb, read that vernier division line which has *both of the two adjacent ones entirely within two divisions of the limb,* as in figure 32 (C). After orienting by a back sight, par. 180, *always release the upper clamp E and turn the vernier A to zero to see if the north point of the needle also reads zero.* This test is to check large errors of a degree or more, due to turning the wrong screw etc.

PLOTTING THE TRANSIT SURVEY.

182. There are two methods of plotting the transit traverse:

1st. *With a protractor.*

2nd. *By means of rectangular coordinates.*

The equipment required for plotting is,—a sheet of drawing paper or cross-section paper, figure 102, p. 196, of sufficient size to contain the area; a T square and triangle, figure 108, scale of equal parts, figure 106, a protractor, figure 107; wax headed needles for plotting points; pencils No. 6 H and H; rubber eraser; pair of dividers, figure 104.

PLOTTING WITH PROTRACTOR.

183. A celluloid protractor, figure 107 (a), or one machine made on card board, should be used. The small brass protractors in instrument sets are too inaccurate.

Assume a point *a*, figure 97, on the sheet to represent the starting point A on the ground and write in parenthesis its elevation, (800). Draw through *a* the line *n s* to represent the meridian (magnetic or true according as the declination was not or was

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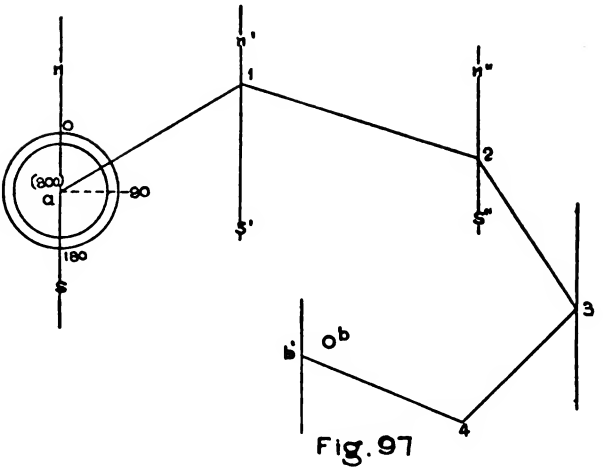

Fig. 97

set off, par. 74). Lay the center of the protractor on *a*, the zero and 180° points on the *n s* line. *With plotting point vertical, prick a minute hole at the edge of the protractor exactly opposite the azimuth reading to station I* (see notes, par. 177). Draw the light indefinite line *a* 1, through *a* and the point pricked. With scale of equal parts, figure 106, or a working scale, see par. 16, lay off the distance A I to scale and prick the point 1. With T square or ruler and triangle draw *n' s'* parallel to *n s*, see par. 200, and continue the main traverse to 2, 3, 4, etc., to *b* as prescribed for I. Having plotted the main traverse, plot in *b. m.* and all side shots in like manner. If the main traverse does not *"close,"* that is if *b'* does not fall on the *b* on the sheet as plotted from the triangulation, adjust the locations and elevations of the traverse stations, as prescribed for plane table traverse, see par. 159, and then plot all side shots from the adjusted stations.

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PLOTTING FROM RECTANGULAR COORDINATES

184. Instead of laying off the azimuth of each course with a protractor and plotting its length to scale along the line joining the two stations, as above described, the traverse courses may be plotted with reference to two lines perpendicular to each other called *"Rectangular Axes."* These lines are the meridian (*n s*), figure 98 (a), and the east

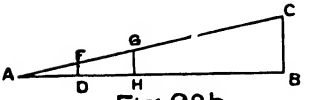

Fig. 98b

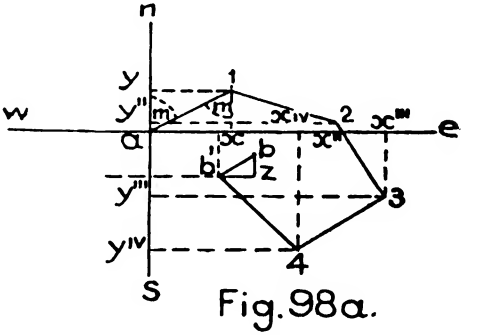

Fig. 98a.

and west line (*e w*). The position of any station, as 1, figure 98 (a), may be located with reference to another station as *a*, by plotting the distance *a x* along *e w* from *a* to the point where a perpendicular from 1 meets the line *e w;* and by plotting *a y* along *n s* from *a* to the point where a perpendicular from 1 meets *n s*. To plot 1, *a x* and *a y* are scaled off and at *x* and *y* perpendiculars are erected to *e w* and *n s* respectively, and the point where these perpendiculars intersect each other is the location of 1. *a x* and *a y* are called *the projections of a 1 on the axes e w and n s respectively.* In the same manner, any other station as 2 can be determined with respect to any other station as *a* or 1.

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Distances measured along *e w* are called *"Departures"* and along *n s*, *"Latitudes."* For instance, *x x''* is the departure of course 1 2. In order to plot by the above method, it is necessary to find the latitude and departure of a course of any length and azimuth.

184. (a) From trigonometry, figure 98 (a), $\frac{ax}{a1}$ =sin *m*; $\frac{ay}{a1}$ =cos *m*.*

ax=*a* 1 (sin *m*), or *the departure of a course equals the length of the course multiplied by the sine of the azimuth.*

a y=*a* 1 (cos *m*), or *the latitude of a course equals the length of the course multiplied by the cosine of the azimuth.* These equations are true for all azimuths, but it will simplify the trigonometrical work, if it be remembered that where the azimuth is in the 1st, 2nd, 3rd or 4th quadrants, figure 99, that the angles *m, n, p, q,* respectively are

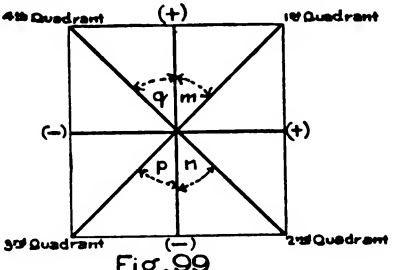

Fig. 99

the ones whose sine or cosine is used. For example, suppose the azimuth is 195°, length of course, 500 feet. Then p=195—180=15°, and the departure, =—500×sin 15°, and the latitude=—500×cos

*See explanation of table 111, p. 342.

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15°. *The signs to be given to the latitude or departures are plus* (+) *when measured toward north or east, minus* (—) *when measured toward the west or south.* In figure 98 (a), the latitudes of *a* 1, 4 *b* are plus (measured north); the latitudes of 1 2, 2 3, 3 4, are minus (measured south). The departures of *a* 1, 1 2, 2 3 are plus (measured east. The departures of 3 4, 4*b* are minus (measured west).

185. *To find the latitude* (*or departure*) *of any course,* pick out from the table of natural cosines (or sines for departures) *Table III,* Appendix, p. 341, the cosine of *the angle less than 90° corresponding to the azimuth,* (see par. 184 a) and multiply it by the length of the course, prefixing (+) or (—) according to the above rule. For example; course 2 3, figure 98 (a), is 800 feet long with an azimuth of 145°30′. What is the latitude and the departure of the course? 180°—(145°30′)=34° 30′=angle *n*, figure 99. From table III, the natural sine 34°30′=.5664. 800×.5664=+453.12 feet. (measured east, hence+)=the departure.

Natural cosine 34°30′=.8241. 800×.8241= —659.28 feet (measured south hence minus) =latitude of the course.

186. Each of the successive courses ending at 2, 3, etc., figure 98 (a), may be plotted from the preceding station, as 2 from 1, 3 from 2, or from the original starting point, or origin, as *a*. Thus the point 4 may be plotted by laying off the departure (—x''' x^{IV}) and latitude (—y''' y^{IV}) of the course 3 4, from

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x''' and y'''; or by laying off the sum ($a\ x+xx''+x''\ x'''-x'''\ x^{IV}$) from a along $e\ w$; and the sum ($a\ y-yy''-y''y'''-y'''\ y^{IV}$) from a along $n\ s$. The advantage of the latter method is that all the plotting starts from one point and there is no accumulation of errors of drafting as in the 1st method. It is evident that the algebraic sum of the latitudes or departures of the courses from a through 1, 2, etc., to any other station, as 4, is equal to *the latitude or departure of the line direct from a to 4.* This gives a most valuable check on the accuracy of the traverse, for if the latitude and departure of b have been previously determined from the triangulation, they should be equaled by the latitude and departure of b' as found from the traverse. If the final station of the traverse falls at b', then the error of latitude$=-b\ z$, and the error of departure$=-z\ b'$. The error of closure$=bb'=\sqrt{(-z\ b)^2+(-b'\ z)^2}$. *The error of closure bb' divided by the total length of traverse ($a\ 1+1\ 2+2\ 3+3\ 4+4\ b$) is called the ratio of error of the traverse and is usually expressed as a fraction with the numerator of unity.* The ratio of error of a traverse with the transit and stadia of $\frac{1}{2}$ to 2 miles should not be greater than $\frac{1}{300}$. *The limit of error* in that case would be $\frac{1}{300}$, because that amount must not be exceeded in the work.

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ADJUSTMENT OF ERRORS.

187. The error is distributed at each station by the following proportion: *Error of latitude (departure or elevation) of any course*: *total error of latitude (departure or elevation) at the end of the traverse*: : *the length of this course*: *the length of the entire traverse.* The corrections should be made as shown in the table par. 188, *by either adding or subtracting so as to reduce the whole error,* before plotting. The adjusted latitudes etc., are then plotted; that is, if b' falls to the south of b, all the latitudes are moved north; if the elevation of b' is too small, the corrections are all added. Since the principal advantage of plotting by latitudes and departures is that errors may be adjusted before plotting begins, it is not necessary to graphically solve the above proportion by similar triangles as was done in the correction of the plane-table traverse, (par. 159); this may be done, however, as shown in figure 98 (b). AB is the total length of the traverse; BC is the error at the end of the traverse; F D, G H, etc., the the errors of courses whose lengths are A D, A H, etc.

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TABLE—COMPUTATION OF LATITUDES AND DEPARTURES OF TRANSIT TRAVERSE IN FIGURE 96.

188. (Not including the side shots)

Point Observed	Bearings	Distance feet	Latitude		Departure		Balanced		From Sta. A.*	
			North +	South —	East +	West —	Lat.	Dep.	Total Lat.	Total Dep.
I	S49°37′E	581		376.4	442.50		—383.22	+436.96	—383.22	+ 436.96
II	N89°14′E	300	4.01		299.90		+ .49	+297.03	—382.73	+ 733.99
III	N69°E	690	247.27		644.20		+239.17	+637.66	—143.56	+1371.65
IV	N88°W	400	13.96			399.7	+ 9.27	—403.51	—134.29	+ 968.14
B′	N65°W	600	253.50			543.78	+246.46	—549.49	+112.17	+ 418.65
	Totals....2571		518.74	376.4	1386.60	943.48	+112.17	+418.65		
			376.4		943.48					
	Difference A to B′		+142.34		+443.12					
	Correct Lat. and Dep. A to B. (found in previous triangulation.)		+112.14		+418.62					
	Corrections....—30.20				—24.5					

Correction of Latitude at end of any course = $(-)\frac{30.2}{2571} \times$ length of course.

Correction of Departure at end of any course = $(-)\frac{24.5}{2571} \times$ length of course.

All stations in the table are moved *west* and *south*.

*The total latitudes and departures are used in plotting from the original origin, see par. 186.

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CHAPTER VIII.

CONTOUR SURVEYING.

189. The plane-table and transit are used for locating contours on the ground and plotting their position on the map as follows, *two distinct operations being performed*:

1st. *Points on the contour are located, using the transit as a level to carry the elevation from the nearest B. M.* The position of the T. P.'s and level stations are not plotted on the sheet.

2nd. *Each critical point located on the contour by the leveling operation is plotted on the plane table sheet.*

With the transit *used as a level* (see leveling, par. 134) a line of differential levels is run from the nearest B. M., figure 100 (a), until a T. P. is set about one foot above the first contour to be located (T. P. II). Having located this T. P. on the ground, a plane table traverse is run from the nearest triangulation or other known station, as A, using the transit for reading the stadia distance only, and plotting the courses *a* 1, 1 2, 2 3, figure 100 (b), on the plane table sheet, until a plane table station, as III, figure 100 (a), is reached where the H. I. of the *transit* will be about 8 or 10 feet above the contour. The plane table and transit being set up side by side (par. 163) at this station, a B S. is taken with the transit (telescope

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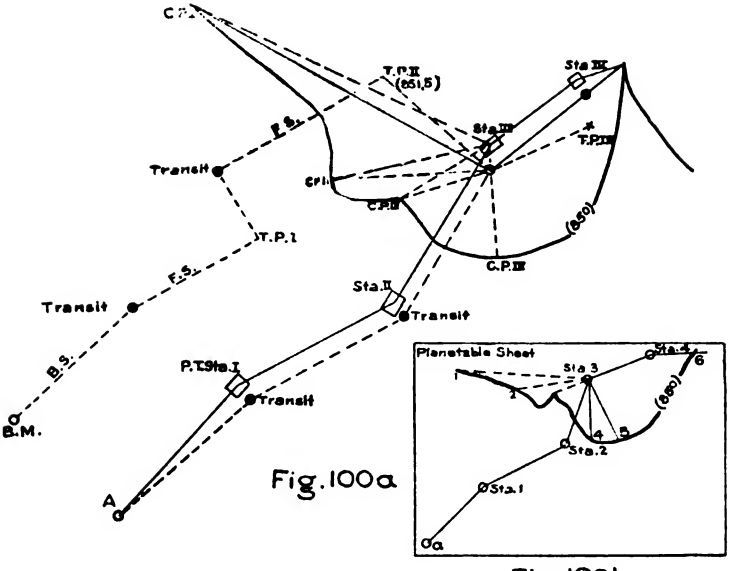

bubble in the center of the tube) on T. P. II, and added to the elevation of T. P. II, giving the H. I. at station III. The elevation of the contour subtracted from this H. I. gives the difference of elevation from the H. I. down to the contour, or *the point at which the target must be set so that the foot of the rod will be on the contour* when the target is bisected by the cross-wires of the leveled telescope. With the target set at this reading, the observer directs the rodman to critical points on the contour as C. P. I, C. P. II, etc., motioning him up or down hill until the center horizontal cross wire is on the target. Each contour point thus found is located on the plane table-sheet, as 1, 2, 3, etc., figure 100 (b), by a sight taken through the alidade for direction, and a stadia distance-reading

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with the transit, plotted in the direction just found. After each stadia-reading the telescope is carefully leveled again by placing the telescope bubble in the center of the tube. Having located all critical points within range of stadia-readings, the work is moved forward by the two steps following:

190. 1st. *To locate a new T. P.* [as T. P. IV, figure 100 (a)] with the transit used as a level.

2nd. *To locate a new plane table station*, station IV figure 100 (a), on the ground and plot it on the sheet, station 4 figure 100 (b).

The level rodman is directed to pick out, about one foot above the contour a T. P. (as T. P. IV) which can be seen from the station III and from the station point in advance, as sta. IV. A F. S. is taken on the T. P. from sta. III. The stadia rodman is now directed to place a plane table station forward along the contour (as at station IV), so that the H. I. at that point, will be about 8 or 10 feet above the contour. This station is plotted as above described. The plane-table and transit are set up side by side at station IV. The plane table is oriented by a back sight on station III, and the work proceeds similarly to the end. The level notes and a record of the stadia readings should be kept as shown below, so that in case the traverse does not close in elevation, or horizontally within about $\frac{1}{300}$, on a triangulation station near the end of the contour, an adjustment of the traverse can be made (see par. 159) and the

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contour points can be plotted from the adjusted positions of the stations.

191. CONTOUR SURVEY NOTES.

		Plane Table Notes			Level Notes				
At Station	Point Observed	Stadia	Vertical angle	Hor. Dist.	Elevation	B. S. +	H. I.	F. S. —	Remarks
⊙ I	B. M.				835.000	10.000	845.000		(Level Stations marked ⊙)
⊙ I	T. P. I				843.625			1.375	(Plane-table stations marked □)
⊙ II	T. P. I					12.000	855.625		
⊙ II	T. P. II				851.500			4.125	
□ I	A	220	—6°30′	213					(No reductions to horizontal made for less than 5°)
□ I	□ II	300	+ 30′	300					
□ II	□ I	300	— 30′	300					
□ II	□ III	500	+1°30′	500					
⊙ III □ III	T. P. II					9.000	860.500		860.500--850.000 = 10.5 = set rod target.
⊙ III □ III	□ II	500	—1°30′	500					
	C. P. I	800	—	800					
	C. P. II	300	—	300					
	C. P. III	150	—	150					
	T. P. IV				851.500			9.000	
	□ IV	800	—	800					
⊙ □ IV	□ III	800		800					
	T. P. IV					8.00	859.500		

192. *Two contours can be run at once* by having two targets on the level rod one contour interval apart, or two level rods with their targets set a contour interval apart. The transit alone could be used, instead of the plane table, to determine horizontal directions but a large part of the topographical training of the eye would thus be lost.

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This method of contour location is not as rapid as that of par. 165, but is of the greatest value in learning to estimate the position of contours on the ground and their map representation, also to estimate distances and elevations, all of which are important in learning to make rapid sketches. *Each distance should be estimated and then checked with the stadia; each elevation estimated and then checked with leveled transit; each contour point, estimated and then checked by the sight on level rod.* Constant practice of this kind will increase a student's knowledge of ground rapidly.

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CHAPTER IX.

INSTRUMENTS USED IN FINISHING THE MAP AND METHODS OF USING THEM.

193. *Kohinoor Pencils*: Numbers 6H and HB (or H), figure 101. The 6H are very hard

Fig. 101

and suitable for drawing fine construction lines; the HB are soft and suitable for drawing heavy black lines as on a tracing to be blue-printed. All of the field sheet should be executed with a well-sharpened 6H pencil, because of the fine lines possible, the ease with which erasures are made, and because of the cleanliness of its lines as compared with those of HB.

194. *To draw a pencil line*: Hold the pencil vertical with its point close to the straight or curved ruler determining the line. To draw an accurate free hand line, such as a contour: rest the right side of the hand on the paper, knuckles to the front. Sketch in with very light strokes toward the body the desired line, correcting it until the exact position desired is secured.

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195. *Drawing Paper*: For plane table work Unchangeable Drawing Board, a heavy paper which does not appreciably change its size under varying atmospheric conditions, is the best. For indoor plotting Whatman Hot Pressed Paper has a fine surface for pencil or ink lines.

196. *Standard Cross Section Paper*: see figure 102, with squares 5 x 5 to the half inch, or Profile

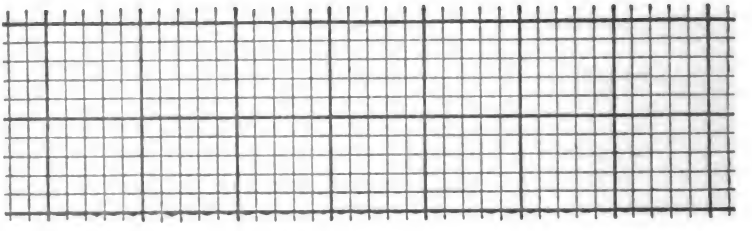

Fig. 102

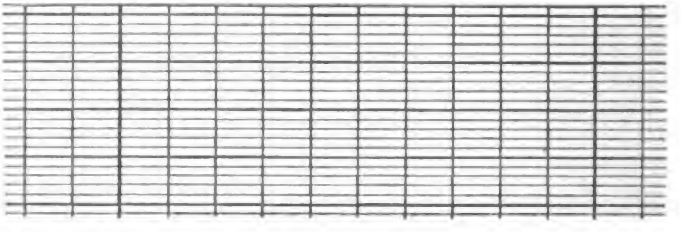

Fig. 103

Paper, figure 103, is the most suitable for the interpolation of contours see par. 167; for plotting profiles, see par. 140; or for plotting a transit survey from rectangular co-ordinates, see par. 184.

197. Universal Pocket Compass and Dividers: figure 104. With this instrument, pencil and ink circles or right lines can be drawn. With the needle point ends in position for use, distances may be tak-

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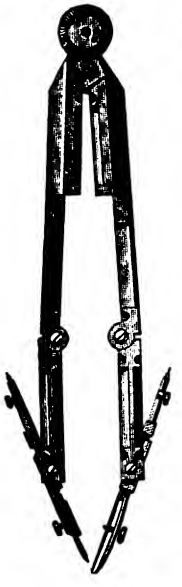

Fig. 104

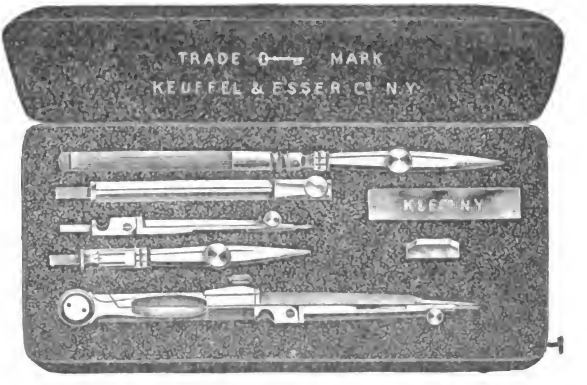

Fig. 105

en from a map or from working scales or scale of equal parts. This is one of the most conveniently carried and generally useful of drawing instruments. It is about the size of a knife and may be carried in the pocket. (Figure 105 shows a convenient set of drawing instruments).

198. *Scale of Equal Parts*: figure 106, has on its different faces scales of 10ths, 20ths, 30ths,

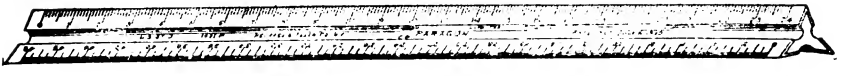

Fig. 106

40ths, 50ths and 60ths of an inch. To lay off a distance with the scale, place the zero on the known point and prick a very minute hole exactly opposite the unknown point, being careful to hold the plotting point (wax headed needle) exactly vertical.

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199. *Circular Protractor,* figure 107 (a), of celluloid. Angles are laid off with it by laying the zero —180° line exactly on the given line on the map, with the protractor center at the given point. The

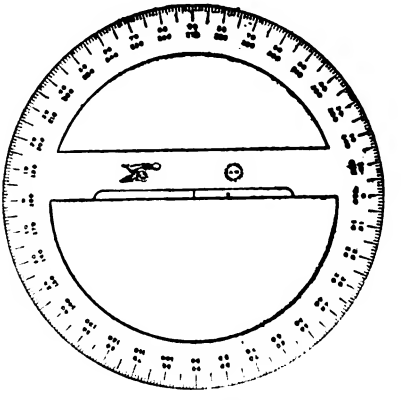

Fig. 107*a*

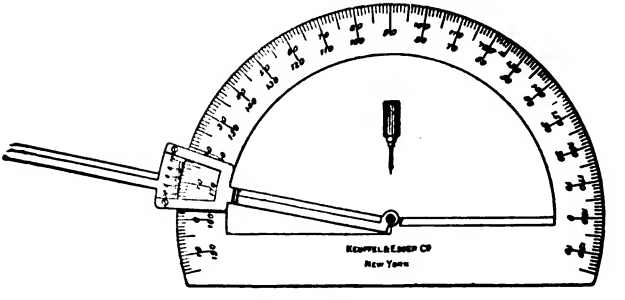

Fig. 107*b*

given angle is marked with a minute hole in the paper opposite the proper angle marked on the circumference of the protractor, and a fine line is drawn from the given point through this pricked hole. Figure 107 (b) is a more accurate protractor.

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200. *T Square and Right Angle Triangle*: Figure 108, for drawing parallel and perpendicular lines. The T head should be used along only

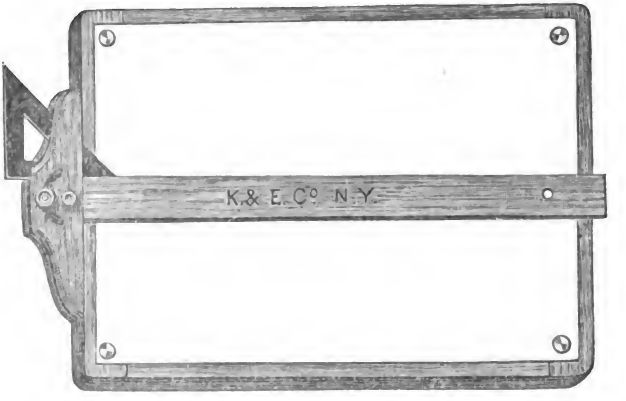

Fig. 108

one edge of the plotting board, because of the difficulty of securing a board with two sides perfectly perpendicular to each other. To draw perpendiculars to the parallel lines, the triangle is placed and moved against a leg of the T square.

201. *To draw a more exact perpendicular* to a given line, through a given point outside of the line, as *a* figure 109: with the compasses figure 104, describe an arc of a circle with the radius *a b*

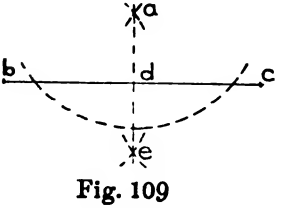

Fig. 109

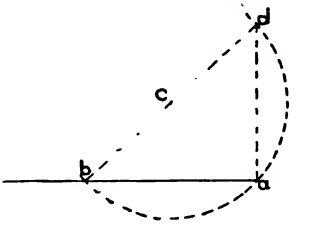

Fig. 110

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cutting the line in *b* and *c*. Bisect *b c* at *d*, (see par. 202) join *a d* which is perpendicular to *b c*. To draw a perpendicular at the end of a line as *a*, figure 110, assume a point *c* outside the line and draw an arc through *a*. From *b* draw the line *b c* to the arc at *d*. *d a* is perpendicular to *a b*.

202. *To bisect a line as b c;* with b as a center and a radius somewhat greater than ½ (*bc*) cut the two arcs at *a* and *e;* cut arcs similarly from *c* at *a* and *e*. Join the points of intersection of the arcs *a* and *e* with a straight line which bisects the line *b c*. This line *a e* is perpendicular to *b c* at *d*, and its construction gives a method of drawing a perpendicular to a line *b c* from a point on that line as *d*, first locating *b* and *c* at equal distances from *d*.

203. *To divide a line into any number of equal parts,* see par. 19.

Right Line Pen, figure 105; this pen is used for drawing lines along the edge of a straight or curved ruler. It is inked by dipping the nib of an ordinary pen in the ink and then inserting it in the opening between the points. The width of line is fixed by the screw on the pen. The two edges should never be forced entirely together. The pen should be held vertical, points close to the ruler's edge, and the line be drawn toward the right. To clean the pen, pass a clean piece of heavy paper between the points. If a very heavy line is desired, first draw two parallel

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medium lines and when dry fill in between them with an ordinary fine pointed pen.

204. *Contour Pen,* figure 112: This is intended for drawing a regular free hand curve such as a contour. Considerable practice is required before it can be used well. The pen hand should rest only

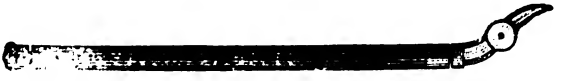

Fig. 112

on the tip of the little finger, and the pen point should rest lightly on the paper, inclined slightly away from the draftsman's body and always following the movement of the hand. The line is most easily drawn away from the body toward the right. With practice the draftsman can draw the lines in any direction.

205. *Tracing Paper*: The pencil field sheet is traced on this paper previous to blue printing the map.

Tracing Cloth is used for tracing where greater durability is demanded. The smooth side of the cloth is intended for ink lines; pencil or ink lines may be drawn on the rough side.

Fig. 113

206. *Drawing Ink,* comes in bottles fig. 113, or sticks fig. 114. The best for general use is India Ink in stick form. This is prepared for use by rubbing the stick

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in a small mortar, figure. 115, with a small quantity of water until the lines drawn appear perfectly black.

Fig. 114

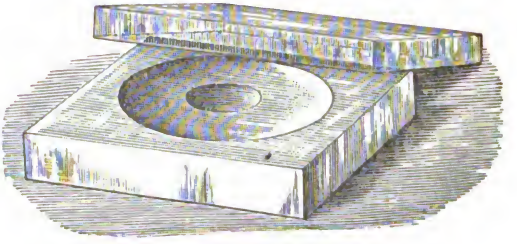

Fig. 115

Thumb Tacks, figure 116, have flat heads so as to be easily forced with the thumb into the drawing paper and are used to secure it to the plotting board.

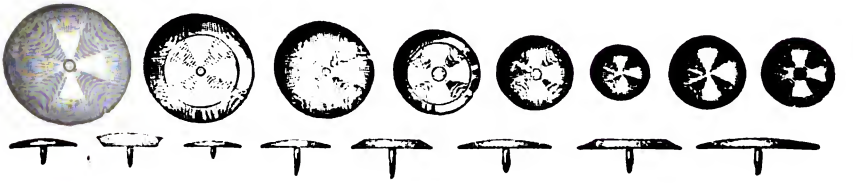

Fig. 116

A sharp knife figure 118, is a good eraser; a soft rubber eraser, figure 117, is necessary for eras-

Fig. 117

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Fig. 118

ing pencil lines; dry light-bread is valuable for cleaning off dirt without erasing lines.

FINISHING THE MAP.

207. Having plotted the contours and sufficient conventional signs to outline the areas of the different growths and inclosures on the plane table sheet (or map sheet if the transit and stadia method is used), a tracing in ink or with an HB pencil is made of the survey on tracing paper, if the map is to be lithographed or blue printed at once; or on tracing cloth if it is to be transmitted to some other place. Blue prints, Brown Prints or Lithographs are made directly from the tracing. In all Military Surveys a large number of copies are usually desired at once, consequently to finish on heavy drawing board an elaborately inked and lettered map is not generally advisable, because the time wasted in this work would be more than sufficient for the tracing.

208. The tracing of the map should contain a *true meridian; magnetic meridian; declination at the date of survey; a plain border* consisting of a rectangle bounded by two lines as shown, figure 119 parallel and perpendicular to the true meridian; *a title showing the office or Bureau under which made; the kind of map; its subject; its location; its authorship; the date of completion; a scale of yards, and one of inches to miles; a scale of Map*

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Distances; the datum (or reference plane) *of elevations.*

209. All lettering on the map should be preferably in *BLOCK,* as in figure 119, vertical or inclined to the right with a slope of eight parts ver-

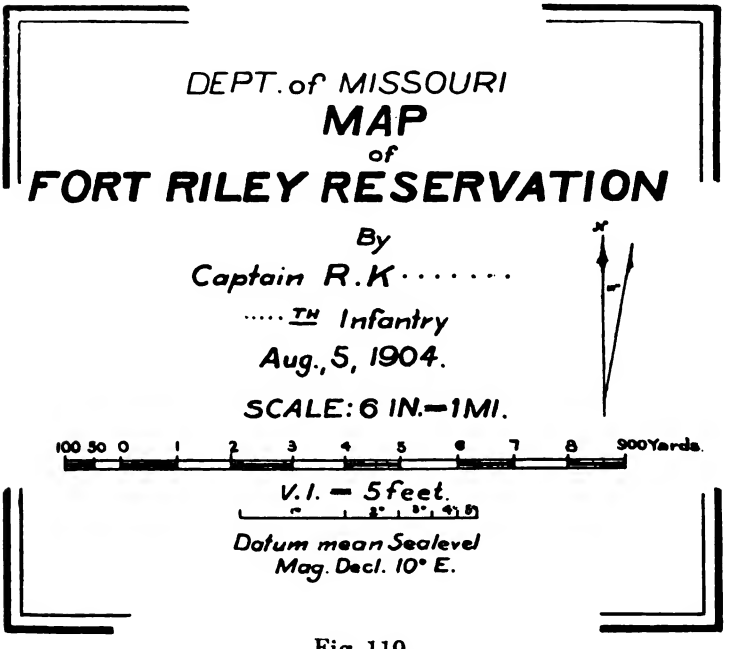

Fig. 119

tical on three horizontal as shown there. For the majority of officers, this style of lettering is most easily and rapidly made. To construct these letters in the title, horizontal lines should be drawn, to enclose the letters, giving the desired height. The letters may be drawn in free hand or with ruler and triangle; with practice they can be made sufficiently neatly free hand. All elaborate ornaments are out of place on a military map.

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CHAPTER X.

REPRODUCTION OF MAPS.

210. Maps may be reproduced photographically or mechanically.

Mechanical Reproduction: *1. By tracing.* Fasten a sheet of tracing paper or tracing cloth over the drawing to be copied. The details will show through and are followed in pencil or ink. The rough surface of tracing cloth takes pencil or ink.

2. *With carbon paper*: Place the sheet of carbon paper over the sheet to receive the copy. Fasten the map on top of the carbon sheet, and trace with an ivory or similar point the lines which are thus impressed on the copy-sheet underneath.

211. *By Squares*: Divide up the original area of the map into a series of squares, one to two inches on the side, depending on the amount of detail to be shown. Number all of the squares serially beginning at a corner of the area. Divide up the sheet on which the copy is to be made into an equal number of squares similarly numbered, with sides of a length proportional to the change in scale (linear dimensions) to be made in the map. That is, the sides to be $\frac{1}{2}$ those on the original map if the scale is to be reduced one-half; double if the scale is to be multiplied by two. Draw in on each square of the reproduction the desired details in the cor-

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responding square of the original. As a rule these locations can be made by eye, but for each very important point two measurements may be made perpendicularly from the nearest edges of the square.

212. 4. *By Pantograph;* figure 120 shows a

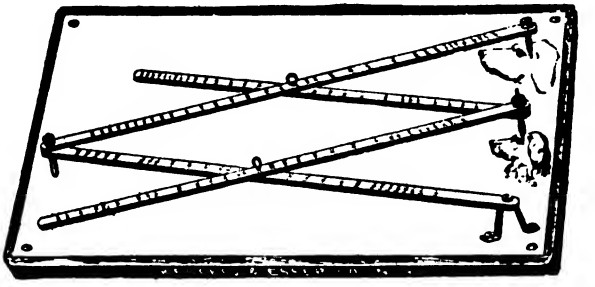

Fig. 120

simple pantograph and its operation. One point is fixed while the tracing point is moved over the original and causes the pencil point to draw the reproduction. The pegs shown at the center of the board are adjustable and may be set at the desired ratio of enlargement or reduction, as marked by holes on the sides of the parallelogram.

PHOTOGRAPHIC REPRODUCTION.

213. 1. *By blue printing*: A sheet of blue paper (sold by any photographer) is secured to the tracing of the map by clips or in a photograph printing frame. It is then exposed to the sun from four to eight minutes, until an edge of the paper has a greenish bronze color, the paper is then removed from the frame and placed in a basin of water, rinsed for three or four minutes under the tap and dried. This is one of the quickest and most

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useful methods of reproduction, because original field sketches made in pencil on tracing paper can be blue-printed at once without retracing. Brown Prints are similarly made.

2. *From a negative*: A negative of the map is made with any kind of camera, in the ordinary way. From this negative, direct prints the size of the negative may be made, or enlargements may be made on bromide paper to any desired size. A description of the details are not within the scope of this book, but such copies can be secured from any photographer. More rapid methods for securing a large number of copies, such as by lithography, are not usually required by Line officers.

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CHAPTER XI.

INSTRUMENTS OCCASIONALLY USED IN MILITARY TOPOGRAPHY.

RANGE FINDERS.

214. The two simplest types of Range Finders used in the U. S. Service, the *Weldon,* figure 121, and the *Penta Prism,* figure 124, are of what is known as the fixed angle and varying base type. They are identical in method of operation.

THE WELDON RANGE FINDER.*

The Weldon Range Finder is a small hand instrument for measuring ranges.

It has three prisms assembled one above the other in a metal case, figure 121. Between the prisms are slots for observing directly a distant object and at the same time seeing in the prism the reflection of another object to be brought into coincidence with the one observed directly. *A compass* is attached to the case as shown, and in the cover used as a handle are cut four notches; these serve to support a pencil in such position that when the needle points due north the pencil will point E. and W., N. E. and S. W., or N. W. and S. E., as the

*This instrument is issued by the U. S. Army Ordnance Department, with instruction book, to each company, troop and field battery. The description of its use in the text is based on this instruction book.

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pencil is laid either transversely or diagonally in the notches.

The *level tube* below the prisms is used in keeping the instrument upright in finding the range. The angle reflected by the 1st (upper) prism is 90°; by the 2nd, 88°51′15″; by the 3rd, 74°53′15″.

The angles of the prisms are so calculated that: (1) *when the first and second prisms are used together,* in the manner explained below, *the range is 50 times the measured base;* (2) *when the second and third are used together the range is equal to 4 times the measured base;* (3) *when the first and second prisms and then the second and third prisms are used together, the range is 200 times the measured base.*

215. *Methods of using the prisms are*: (a) as shown in figure 121 with the apex of the prism toward the eye of the observer. The reflection to the right of the observer is to be sought for in that side of the prism which is farthest from the object, see 0′. This method is preferable and should be used when the object whose range is to be measured is to the right of the observer; (b) With the apex of the prism toward the object whose range is sought. This method will be used when the object whose range is to be measured is to the left of the observer.

To obtain a general idea of *the method of using the range finder,* stand so that your right shoulder points toward the distant object, whose range is desired. Holding the instrument by the cover, look

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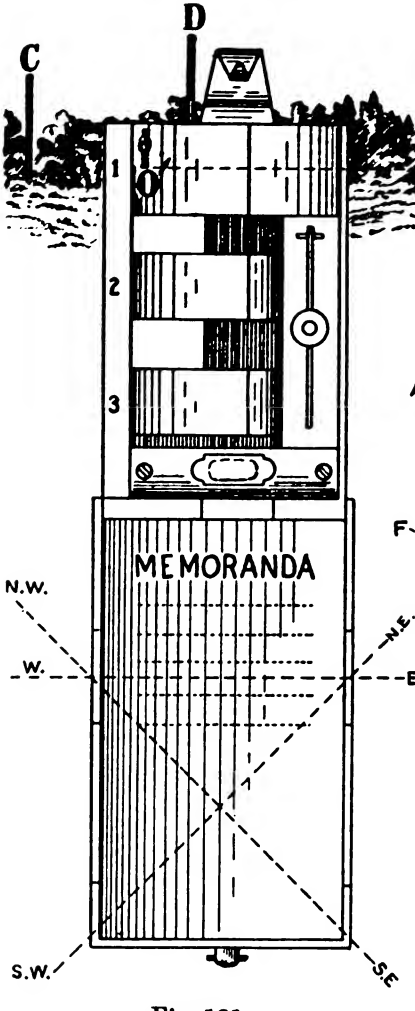

Fig. 121

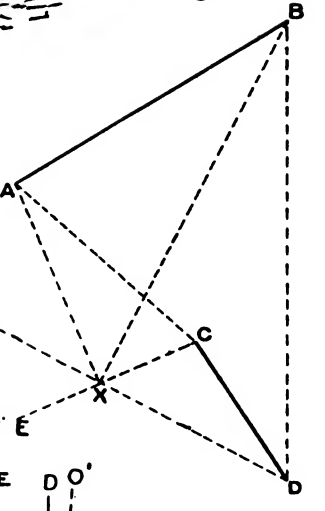

Fig. 123

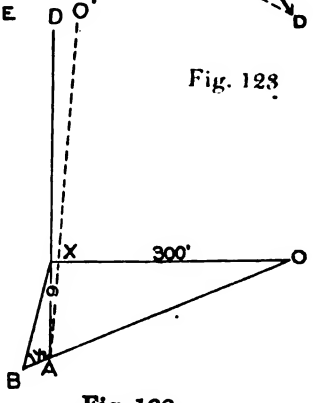

Fig. 122

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with your right eye straight in the prism, until the object sought is seen at 0′, figure 121.

A little practice may be required to find the object. You will note several images, but only the one desired will remain stationary when you rotate the instrument about a vertical axis. You must now cause the reflected image to coincide with some object as D, figure 121, immediately in front of you, looking into and over the prism at the same time. To accomplish this you move to your right, or left, backward or forward. When you have brought the reflected image exactly under the object seen direct, a right angle has been thus formed between the line X O and the line X D, figure 122. Looking in the second prism (2) you see that the reflection of O no longer lies under D, but to the right of it at O′, figure 122. To obtain the range you must now move back on the line D X until the image of O in this second prism falls under D. When this occurs mark this point on the ground, A, and measure the line A X. This being multiplied by 50 equals the range XO. For example if X A =100 yards; X O=5,000 yards, etc.

216. To make a correct angle the *reflected object should be kept upright,* and the reflected horizon as level as it is in nature; for if the instrument be held so that the ground reflected appears to slope when it is really level, or made to appear level when it slopes, the required angle will not be made. Figure 121 shows how coincidence is made with the object in front of you. Thus if an object O, appears

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to your left of D, you can bring O directly over D by moving straight forward if D is distant, or to the right if D is near at hand. If O appears to your right of the object in front, C, move to your rear or to your left until the alignment is perfect. Shade the instrument from the sun with the unoccupied hand.

When you come to take long ranges, you will find that the reflection of the range points approaches the direction point more slowly than when taking short ranges. To get accurate coincidence, it is well to retire or advance until O and D appear to pass each other, then move back to make the exact coincidence. The direction point D should be at least 100 yards distant, and if no natural object is available an assistant may be stationed or a picket placed instead.

217. Problem 2. *To calculate a long base by measuring short base one-fourth its length,* figure 122: If the base X A is very long, or the ground is such as to prevent an accurate use of the tape, a Base B A is measured with the *third prism*: Mark X and A with pickets; move back from A towards B, keeping A and O in line, until the images of O and X coincide. Measure B A, then X A=4 BA, and X O=200 BA.

Problem 3. *To find the distance between two points without occupying either of them,* figure 123. Set a picket at X, and from it as a fixed point with a direction point, F, at right angles to B X, lay off and mark the extremity of the base X D (as though

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taking the range of X B). Similarly from X, using E as direction point locate C. Measure C D and A B=50×CD, from similarity of the triangles ABX and XCD.

THE PENTA PRISM RANGE FINDER.

218. The problems discussed in connection with the Weldon are solved in the same manner with the Penta Prism Range Finder, except such as problem 2 which involves the use of the 3rd prism.

Fig. 124

Figure 124 shows the Penta Prism Range Finder and figure 125 shows how rays of light are re-

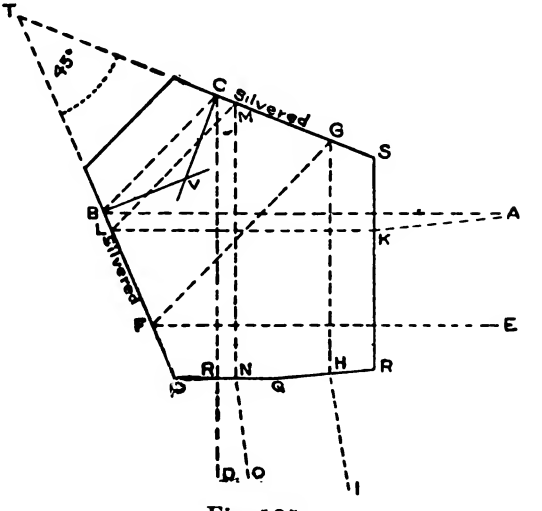

Fig. 125

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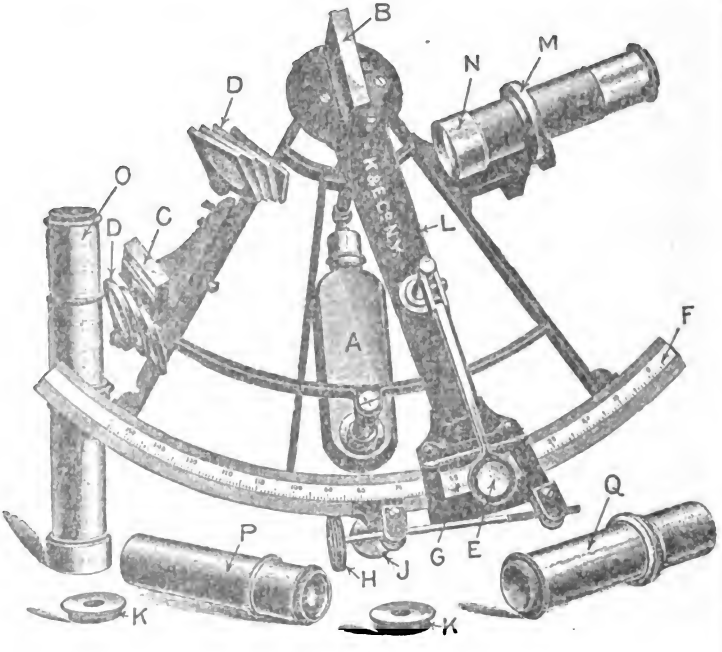
flected by it through 90°, as ABCD and AKLM NO; or through 88°51′15″, as EFGHI. The face



A Handle	J Clamp Screw
B Horizon Mirror	KK Neutral Glasses for Telescopes
C Index Mirror	L Index Arm
DD Neutral Glasses	M Telescope Holder
E Reading Lens	N Star Telescope
F Graduated Arc	O Inverting Telescope
G Vernier	P Eye Piece for Telescope
H Tangent Screw	Q Sighting Tube

Fig. 126

P R, figure 125, has a movable cover shown in figure 124. When P Q (stamped R on the Range Finder) is open, a right angle is formed; when Q

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R is open the angle 88°51′15″ is formed. This Range Finder, consisting of one solid piece of glass about three inches square, is very conveniently carried and can not get out of adjustment.

To obtain coincidence hold the prism horizontal with the face R S toward the direction point, and look over or under the prism at the Range Point securing coincidence as with the Weldon, and using the same precautions in taking the observation.

THE SEXTANT.

219. Figure 126 shows a sextant and a list of its parts. It is a hand instrument for measuring angles and may be used in range finding by setting the index to read the angle reflected by the Weldon Range Finder or by reading the acute angle of any convenient right triangle and solving the triangle with the Slide Rule. Its most valuable use in surveying is in solving the three point (resection) problem, see par. 155, for the location of points over bodies of water where soundings are taken. It is universally used for determining the altitude of heavenly bodies in astronomical problems at sea. *The pocket sextant, figure* 127 is better suited for military surveying work because of its compactness. It is of the same construction as the large instrument, except that the working parts are enclosed in a metal case. *The principle of the sextant is as follows*: Rays of light coming from an object and falling on the index mirror, B, figure 126 are reflected in succession from the two mirrors B and C, with the result that

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they pass into the telescope bent from their original direction by *twice the angle between the mirrors.* The observer looking through the telescope sees the reflected image of one object in the horizon glass C and at the same time can see *directly through an open slit in this mirror* the unreflected image of the other object. By moving the index arm L, until the images of the directly seen and the reflected objects coincide in the telescope, the angle marked

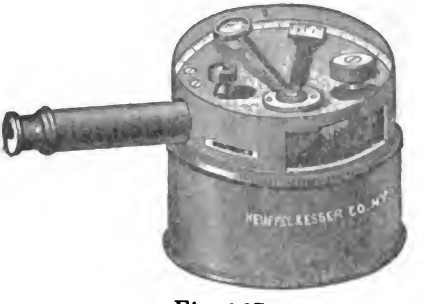

Fig. 127

by the vernier index G on the arc, F, is the angle between the two objects sighted. In order to allow for the double angle through which the rays are bent and yet give the correct angle reading between any two points, the arc is marked in degrees for *each actual half degree space.*

219 (a) *To Read an Angle with a Sextant,* figure 126: With the right hand, grasp the handle A and place the graduated arc, F, approximately in the plane of the two objects to be sighted and the eye. Sight the less distinct of the two objects directly through the telescope and the unsilvered part of the horizon glass, C. Now with the left hand (keep-

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ing the object directly sighted always in view), move the index arm slowly back and forth until the image of the double reflected object coincides with that of the object seen unreflected. Clamp the index arm, by J, and read the vernier, G, thus securing the angle between the two objects. If the two images can not be made to exactly coincide (pass over each other), the sextant is not in the plane of the two objects and the eye, and must be thus placed by being rotated, perpendicularly to the plane of its arc. The angle read will not be a horizontal angle unless the two objects sighted are in the horizontal plane of the eye.

SLIDE RULES.

220. The *slide rule* is an instrument of such general usefulness to officers and non-commissioned officers of all arms of the service, that it is considered advisable to insert a brief discussion of it here. The problems that can be rapidly and easily solved with the slide rule are almost unlimited in number. Some of these are: questions of visibility (par. 41), latitudes and departures from azimuth and length of course (par. 184), square roots, cube roots, powers, all problems of multiplication, division and proportion. Figure 128 shows the usual 10 inch type, and figure 129 a very convenient circular form called the Halden Calculex.*

*The type figure 128 is sold by Keuffel & Esser, with book of instructions from $1.00 to $5.00. The Halden type, with book of instructions both in a leather case the size of a watch, is sold by Eugen Dietzgen Co., New York for $5.00.

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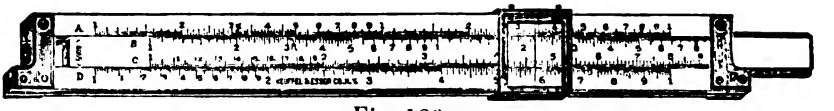

Fig. 128

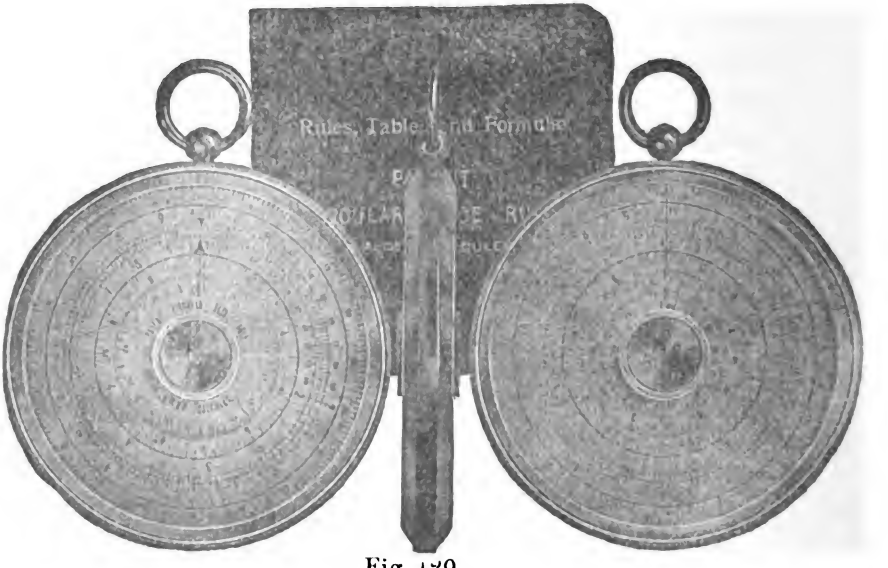

Fig. 129

The instruction book contains a full explanation of the construction of the Slide Rule and simple methods for all forms of calculations. To use the Rule you need only learn the method of setting for the particular class of problems to be solved, and this can be done in ten or 15 minutes.

Scales A and B are identically graduated as shown in the figure, beginning at the left from 1 to 9 at the middle and again from 1 to 10 toward the right. These units are subdivided into decimal parts. In solving any problem the marked units may be taken as *units, tens, hundreds or thousands,*

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and the intermediate divisions given corresponding values. For example if the left 1 is taken as 1000, 2 is 2000, 3 is 3000, etc.; the middle division between 1 and 2 would be 1500 and each smallest space would be 20. The *slide* (scales B & C) is for the purpose of joining a given number of spaces on to any other given number of spaces taken on the rule (scales A or D). Just as if we marked off three inches on a sheet of paper, and taking two inches on another slip of paper joined this space of two on the former of three, thus indicating a total length of five on the 1st sheet. On the Slide Rule. however, the graduations are so divided that *the addition thus of 2 on the rule and 3 on the slide gives the product of 3 and 2 or 6.**

To multiply two numbers together: place the index (left or right line) of the rule opposite one factor, and opposite the other factor on the slide find on the rule the product. To multiply 3 by 2, place left or right index opposite 3 on rule, and opposite 2 on slide find six on rule.

In a similar manner, if we have a space of 6 on the rule and move the slide until its three mark is opposite the index of the rule, then looking opposite 6 on the slide we find 2 on the rule.

To divide one number, a, by another, b: set *b* on the slide opposite the index on the rule and oppo-

*The graduations on the slide rule are according to what is known as a logarithmic series, giving the product of any set of numbers by the addition of their logarithms, or the quotient of the two numbers by subtracting their logarithms.

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site *a* on the slide find the quotient on the rule. $\frac{6}{3}$ =2, set 3 on the slide opposite the index on the rule, and opposite 6 on the slide find 2 on the rule. *Note that in multiplying, always set the index of the slide opposite a number on the rule; in dividing, the index of the rule opposite a number on the slide.*

When it happens that after any setting, the slide does not extend far enough along the rule to give a reading opposite the desired line of the rule, proceed as follows: Set the runner, see fig. 128, so that the scratched line on its transparent face is exactly over the index (end division line) of the slide. Having thus marked this index's position, move the slide *its entire length,* bringing the other index under the scratch of the runner. The desired reading can now be found opposite a division or the rule. The above operation has the effect of making the slide twice as long as it actually is.

221. The greatest value of the Slide Rule is in solving proportions, and it is of great importance to keep in mind that no matter how the slide is set *all the numbers on the slide bear the same proportion to their coinciding numbers on the Rule.* Let us take the ratio of 2 to 4. Draw out the slide toward the right until 2 on A is exactly opposite 4 on B, then between every pair of coinciding numbers the same ratio exists 1 : 2, 3 : 6, 42 : 84, etc. It is evident therefore that if we set the two first terms of a proportion opposite each other on the slide rule, we shall find the third term on the slide coinciding with the fourth term on the rule. The

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scales C and D are graduated so that the divisions are the square roots of those opposite on A and B. For instance under 4 find $\sqrt{4}=2$; under 9 find on D $\sqrt{9}=3$, etc. It is preferable to solve proportions on C and D rather than on A and B on account of the wider spaces and consequently more accurate results. We have therefore the following general rule for solving proportions:

$$\left\{\begin{matrix}\text{Any number}\\ \text{on C}\end{matrix}\right\} : \left\{\begin{matrix}\text{the number un-}\\ \text{der it on D}\end{matrix}\right\} :: \left\{\begin{matrix}\text{any other num-}\\ \text{ber on C}\end{matrix}\right\} : \left\{\begin{matrix}\text{the number un-}\\ \text{der it on D}\end{matrix}\right\}$$

Or diagrammatically stated:

C	set 1st term	under 3rd term
D	over 2nd term	find 4th term

Example: 12 : 21 :: 30 : X

C	set 12	under 30
D	on 21	find 52.5 answer

To solve visibility problems: Set the number of inches between the point of observation and obstructing point on the rule opposite the drop in feet of the line of sight to the point on the slide and then opposite any other number of inches on the rule read the drop in feet on the slide. This gives the most rapid method possible of solving the proportions involved in determining visibility, since a half dozen or more tests can be made along any line of sight in a minute or two. The edge of the slide rule has a scale of inches which is laid along the line of

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sight to show the distance of any point to be tested while from the face you read off the height of the line of sight for this horizontal distance.

222. *Latitudes and Departures*: On the opposite side of the slide from B C are found scales of angles. Without going into reasons, the following is the *rule for finding the departure of a course a* feet long with a bearing of x degrees: Set the index of the slide scale, S, under a on the rule (A), and opposite the angle x, on S, read the departure in feet on A.

To find the latitude of course a feet long, with bearing x degrees: Set the index of slide under a. Opposite $(90°—x)$ on the rule read the latitude on A. The latitudes and departures can be found thus with the slide rule in about one-tenth the time required using tables. The book of instructions gives clear and simple rules for solving each class of problems, so that no one should think the slide rule is too difficult to learn for every day use.

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PART III.

CHAPTER I.

MILITARY SKETCHING.

223. *Military Sketches* are rough topographical maps of a given area, showing in great detail the present existing features of military value with sufficient accuracy to meet all military requirements. They are intended to give to military commanders detailed information of the immediate zone of operations, and to furnish the basis for reports of reconnaissances and scouts; for the issue of orders for posting troops in position, for launching an attack, for organizing a march of concentration, etc.

224. Sketches are of the greatest importance when the operations take place in territory of which no maps exist, but in any case are essential to amplify and bring up to date the information given by existing maps. Most civil maps are on too small a scale to meet all the tactical requirements; they are also deficient in the details necessary for military purposes, such as new roads, buildings, wire fences, growing crops. *Civil Maps* often show no elevations, or their contour interval may be too large to show important cover, and the contours are usually spaced uniformly from top to bottom of all hills regardless of the actual slope of the ground, thus furnishing meagre information of the cover afforded or the best line to be held. Military sketch-

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es, on the contrary, should show convex, concave and uniform slopes true to nature, and all details valuable in military operations.

SCALES OF MILITARY SKETCHES.

225. *The Field Service Regulations* prescribe that the *normal system* of scales shall be used in making field sketches as follows:

226. *Position* and *outpost sketches,* 6 inches=1 mile, contour interval 10 feet; *road sketches,* 3 inches=1 mile, contour interval 20 feet. *Place sketches* should be made on the 6 inch scale, with 10 foot contours, unless they join on to and extend road sketches, in which case they are made on the scale 3 inches=1 mile, 20 foot contours. The use of this system is of great importance to the beginner in sketching, because a given M. D., par. 25, between contours always represents the same slope, no matter which of the scales is used. If the sketcher will learn the M. D. corresponding to *one, three, five* and *seven* degrees of slope, so that he can plot them accurately from memory, he can draw contours rapidly to show slopes from 1 to 14 degrees. For example, ½ degree slope is represented by two lengths of the 1 degree distance; 2 degrees by ½ the 1 degree distance; 3½ by twice the 7 degree distance, etc. This ability to immediately convert ground slopes to map distances, as will be seen later on, is the key to rapid sketching.

MEASUREMENTS MADE IN MILITARY SKETCHING.

227. (1) *Distance,* (2) *Horizontal Direction,* (3) *Slope,* (4) *Elevation.*

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Methods of Distance Measurement Used in Sketching. The units used are: (1) The sketcher's stride in inches; (2) the distance in inches passed over by the sketcher's horse per minute at a trot, and at a walk; (3) the distance in inches passed over by one revolution of a wheel; (4) 100 yards as estimated by the skilled sketcher.

228. 1. *The Stride.*—In all position and outpost sketching, except where the time is too limited, the work is done by the sketcher dismounted making the controlling measurements by pacing. Accurate measurement by pacing depends on the skill of the sketcher in maintaining a uniform length of pace. Good pacing should not be in error by more than 3 per cent on courses averaging from 300 to 800 yards.

229. *To Determine the Scale of Strides.*—The sketcher should lay out an accurately measured distance from one-half to two miles long, over ground of varying slopes. He should then pace this course in both directions at least twice, keeping a record of the number of strides with a tally register, Figure 130, held in the left hand. Each time his right foot

Fig. 130

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comes to the ground the left thumb presses the registering lever. This system of keeping the record is the best possible, because the left hand is free to handle the register in the sketching work, and after a very little practice will automatically press the lever as the right foot strikes the ground, which occurs as the left hand reaches the forward point of its swing. The more nearly automatic the work of pacing and recording strides becomes, the more completely can the sketcher's attention be devoted to observing the details and configuration of the ground and the shape of the contours so essential for good sketching. Also the more automatic the pacing becomes, the more uniform and accurate will be the results. The sketcher should, from the first, remove his attention from the act of recording the strides, because by no other means can he secure uniformity; and in the actual work of sketching his mind is necessarily devoted to other things, such as the observation of the ground, the picking out of critical points, the estimation of elevations and offsets, etc. Having paced the course several times, the sketcher takes his average number of strides for the course and divides it into the total distance. The quotient is then used as his length of stride in the construction of working scales of strides. For example, suppose the distance is 2500 yards; and the recorded number of strides, 1560, 1580, 1550, 1570, 1540. The average is 1560. 2500 yards=90000 inches. $\frac{90000}{1560}$=57.6 inches, the length of one stride.

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With this a scale of strides at 6 inches=1 mile is constructed.

R. F. $\frac{1}{10560}$, $\frac{1 \text{ inch}}{\frac{(10560)}{(57.6)} \text{ strides}} = \frac{1 \text{ inch}}{183.33 \text{ strides}}$, or 5.45 inches=1000 strides, from which a working scale is constructed as in Problem 1 (b) p. 9, Map Reading.

230. The sketcher now proceeds to make a traverse over the measured course, using this working scale for plotting. On completing this traverse, he measures it on his sketch and should find it to be 2500 yards to scale. If the plotted length is not 2500 yards, the stride used in sketching is not of the same length as that found in pacing the course, and the true length must be determined. Suppose the scaled distance is 2600 yards, then the length of the stride assumed in making the working scale is too long and must be reduced in the proportion $\frac{2500}{2600} \times 57.6 = 55.3$ inches=the true length of stride.

After two or three sketches have been made and tested thus over courses of known length, the stride for all future work will be determined. It should be borne in mind that *uniformity of length of stride and automatic recording* are the important things, because then the parts of the sketch are true relatively though on a slightly larger or smaller scale than intended. However, it is much easier to contour the sketch if the distances plotted are actually on the scale intended, because then the number of

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contours and their spacing show correctly *the true difference of elevation* and *the true slope* between any two points.

231. 2. *Horse's Walk and Trot.*—It has been found by several years' experience at the Service Schools that horses may be rated at the walk or trot so as to furnish measurements of distance with an error not greater than 5 per cent. This is sufficiently accurate for road sketches, except possibly on the main routes of a combined road sketch where carts are preferably used. The normal method of making road sketches is mounted, therefore, except for one or two preliminary sketches. The method of determining distance by the rate of the horse's walk and trot is more accurate than is possible by counting the horse's stride and sufficiently accurate for military road sketches, as the errors tend to compensate one another. Counting strides is also objectionable because the attention which must be devoted to it prevents that study of the ground so essential in road sketching. Unless the horse has a very steady walk and trot, it will not take a sufficiently uniform gait of its own accord. The sketcher must, therefore, carefully observe his horse's gaits and be able to *know if the horse is moving too fast or too slow.* For instance, a horse moves freer on starting out in the morning than later in the day when he is tired. His gait is slower going away from his barn than coming home, especially if it is near feeding time. A horse moves slower and more uniformly when alone on the road than when

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other horses are passing him. Two horses of equally uniform gaits trotting side by side move with greater uniformity than either one of them alone but if one of the pair is much more steady than the other, this one should be ridden in advance. The sketcher should learn the peculiarities of his horse and take necessary measures to keep him up to his proper gait when he lags and hold him in when he rushes ahead.

232. *To determine a horse's rate,* he should be ridden over accurately measured courses until the time required on any of the tests for the distance does not differ from the average by more than 5 per cent. This should be done for the walk and for the trot. In these tests, the sketcher should observe carefully the gaits until he is able to know when the horse is going at the proper rate and cause a change of gait when necessary. If the sketcher is to have an assistant in sketching, the two horses should be tested together and in the manner in which they will later be used. For instance, if the assistant is to ride beside the sketcher, the horses should be rated thus. If the assistant's horse is to keep the gait going in front, they should move in this order in the test.

It is sometimes found of assistance in keeping a uniform gait for the sketcher to rise to the trot because this enables a good estimate to be made as to the uniformity of time of the strides. Care must be used not to rate the horse faster than he can travel for a day's work. Most of the time in mounted

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sketching is spent at the halt, so rapidity of gait is not of much advantage. A slower gait gives better opportunity to the sketcher to study the ground forms and details. The trot is the habitual gait in mounted sketching and should be always used except on steep slopes. No correction need be made for grades, even in hilly country, because they do not appreciably affect the horse's rate; but the rating should be done over ground of the same nature as that to be sketched. Where the grade is steep enough to make any allowance, it is necessary to take up a walk to protect the horse from being staved up in the shoulders; and, therefore, an accurate determination of the rate of the walk up and down steep hills is very important and should be found under these conditions. As soon as the sketcher is positive of the horse's gait, he constructs scales of minutes, halves and quarters, see problem 3, par. 19. The scales should be tested in actual sketching, as described for the stride, because this work often causes a modification of the gait.

Rules for correcting scales: *A sketch smaller than intended (scale too small) is caused by having assumed the horse's gait to be slower or the stride shorter than they actually are.*

Should it be required to *make a mounted sketch on an unrated horse* when no time is available for rating, the sketcher should use the scale of average walk and trot; *a mile in sixteen minutes at a walk; and in eight minutes at a trot,* see figure 136, p. 242. He should be able to keep the horse very close to

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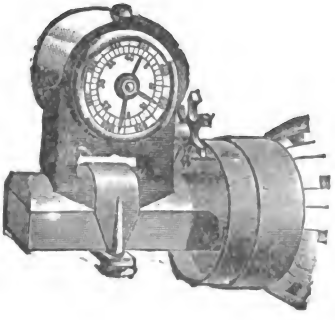
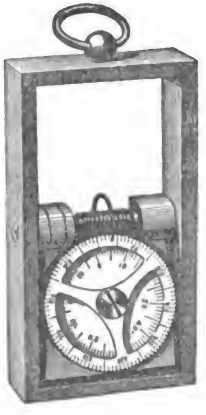
these gaits, by his knowledge of horses' gaits in general.

233. 3. *The Distance Passed Over by a Revolution of a Wheel.*—This method of determining distance is of great value in making road sketches, especially in combined work, because of the uniformity secured. The length covered per revolution is best determined by driving over a measured course and *dividing the length of the course by the number of revolutions.* This gives better results than measuring the circumference of the wheel, which slips and has side motions along the road. The rating course should be over average rolling ground to prevent measurements in the actual sketching from being too long on the hills where the wheel measures along the slope instead of the horizontal distance as it should. The number of revolutions is recorded by an *Odometer,* fig. 131 (a), attached to the axle of a front wheel and oper-



131*a*



131*b*

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ated by a steel pin driven into the end of the hub. This type is called the *Bell Odometer* and registers miles and fortieths of a mile (44 yards) and, as each mile is completed, a bell rings. This type is more accurate than the pendulum type usually furnished, figure 131 (b), and is very convenient for sketching because the readings are easily visible from the seat of the wagon. With this odometer a scale of miles and fortieths would be constructed so that plottings would be directly from dial readings. Readings are continuous up to 1600 miles, and the most serious objection to this type is that there is no device for setting back to zero. A Veeder odometer reads tenths of a mile, and may be set back to zero. The pendulum type is practically useless in sketching, because it must be removed from its case for each reading. In case no odometer is on hand, a piece of white cloth may be tied around the tire and the rotations of the wheel be recorded on a tally register by an assistant. If there is no measured course available over which to determine the length of one revolution, the circumference of the wheel is found by multiplying the diameter by 3.1416.

234. 4. *Estimation of Distances.*—An essential qualification for a rapid and accurate sketcher is the ability to estimate distances with less than ten per cent error up to about six hundred yards and within fifteen per cent up to a mile. This can only be acquired by constant practice in making estimates of various distances and then verifying the

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estimates by accurate measurement. The best possible method is in connection with stadia surveying, which gives instantly the true distance to the point observed and enables the sketcher to determine whether his natural tendency is to make his estimates too large or too small. Even if no surveying work is done, it will pay the sketcher to secure a rodman and a transit and make a series of estimates verified by stadia readings. If the rodman is mounted the readings can be taken rapidly at widely differing distances and across different kinds of ground without loss of time. The sketcher can, at the same time, estimate and check slopes by vertical angle readings; and differences of elevation, using the Cox Stadia Computer, p. 127 Military Topography. A few hours' work occasionally with the transit and stadia in practicing estimates of distances, slopes and elevations will add materially to the sketcher's ability.

Estimates of distance should be made in yards and one hundred yards should be definitely fixed in mind as a reference unit. In all estimation of distance the sketcher should bear in mind the effect of conditions of ground and light on estimates.

235. *Objects appear nearer than they really are*:

1. When the sun is behind the observer and the object is in the bright light.

2. When seen over a body of water, snow or level plain.

3. When down below the observer.

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4. When in high altitudes and very clear atmosphere.

In the above cases add to the normal estimate.

Objects seem further away than they really are:

1. When up a steep hill from the observer.
2. In poor light such as fog.
3. When seen across undulating ground.

In the above cases subtract from the normal estimate.

Objects are distinguishable to average eyes at the following distances:

Nine to twelve miles, church spires.

Five to seven miles, windmills.

Two to two and a half miles, chimneys.

Two thousand yards, trunks of large trees.

Six hundred yards, individuals of a column.

Five hundred yards, individual panes of glass in windows.

Four hundred yards, arms and legs of dismounted men.

Each man's eyes are different and the sketcher should learn for himself at what distances objects can be seen by him and their appearance at different ranges, by *noting objects on the ground and scaling their distances from a good map.*

Telegraph and telephone poles are usually set at fixed distances along any one line, so that the sketcher, by pacing one interval (or better, by dividing a known distance by the number of poles contained, to secure their average distances apart), may then make accurate measurements as far as

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the poles are visible. There may be lines of railway telegraph, of different telephone companies, power lines (distinguished by very large insulators) and street railway lines. The average distance between street railway or telephone poles is usually one hundred feet. The interval on each class of lines in the vicinity of his station should be learned by the sketcher. In those parts of the country where the land is divided into sections the *hedges* and *fences* are usually at 220, 440, 880 yards apart.

THE ESTIMATION OF GROUND DISTANCES DIRECTLY AS SPACES ON THE SKETCH.

236. When the sketcher has learned to estimate distance with accuracy, he plots these estimates with his scale of yards to locate detail on his sketch. The next step in his training is in learning to estimate the map space corresponding to a given ground distance. This is rapidly acquired by using a scale of hundreds of yards as the unit of plotting. The map distance of 100 yards is .34 inch, at 6 inches to 1 mile, or about $\frac{1}{3}$ inch; 100 yards at 3 inches to 1 mile is about $\frac{1}{6}$ inch. The sketcher should plot, by estimation, 100 yards, then test it with his scale and repeat until he can do it with no appreciable error. It is then easy to plot half miles and miles by estimating $1\frac{1}{2}$, 3 or 6 inches, for representing distant objects not required to be exactly located. The greatest importance of estimating directly the map equivalent of 100 yards, and hence its multiples, is in plotting contours on the sketch directly from their estimated positions on the ground, see par.

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274. Facility is acquired in this estimation of the ground location of contours and their map representation, by taking an accurate map made on the normal scale system, and having estimated the contour's ground position and then having drawn as accurately as possible its map equivalent, compare the result with the same contour on the map. Repeat these steps until you *can trace with accuracy the contour on the ground and plot it as shown on the map.* It will soon be possible to almost imagine you can see the contour following the various curves on the ground.

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CHAPTER II.

SKETCHING METHODS OF MEASURING THE HORIZONTAL DIRECTION OF AN UNKNOWN POINT FROM A KNOWN POINT.

237. *B is Located from A using the plane table method,* by pivoting the ruler on *a* and directing it toward B, figure 147, p. 284, then drawing a line along the ruler in this position, on the oriented Drawing Board, par. 268. This plots the angle made by *a b* with respect to the magnetic meridian without an actual reading of its value in degrees; and is the method constantly used in what is known as the plane table (or sketching case) method of sketching. This method is the one most generally used, and is advocated in preference to all others on account of its greater accuracy, simplicity and rapidity. The plane table method and the compass and protractor method have been tested side by side for a number of years at the Service Schools, until now every one prefers the former, see par. 240.

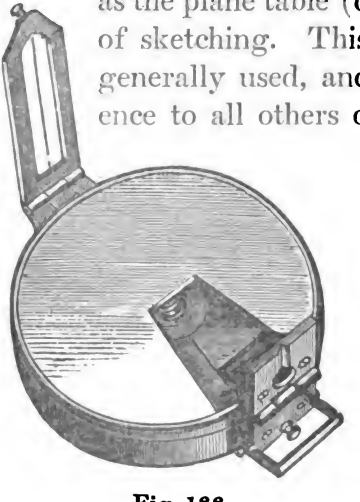

Fig. 133

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2. By reading the azimuth (angular direction with respect to the meridian) of B from A with a Box Compass,* or Prismatic Compass, figure 133. The angle read is then plotted by means of an Abbott's Protractor, figure 134. In reading a box

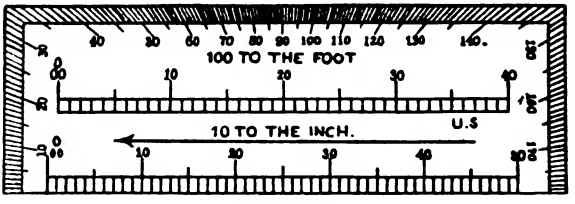

Fig. 134

compass the needle should be damped, by pressing the left thumb down on the stop several times, so that it will settle correctly. To save time, the reading may be taken at the middle of the swing of the north end of the needle.

*To read an azimuth with the box compass, partly close the lid until it makes an angle of about 120 degrees with the plane of the compass face. Then hold the compass in the left hand, in front of your body, and you will be able to see the reflection of the sighting line (*a-b* figure 12, Map Reading) in the glass cover. This reflection of *a-b* should be made to pass through the pivot while *a-b* is pointed toward B, at the time the reading is taken. The reflection will lie through the pivot only when the compass face is horizontal, thus giving the true horizontal angle desired.

To read an azimuth with the prismatic compass: The two sight leaves are revolved into position perpendicular to the face of the compass. This brings the prism directly over the graduated circle on the card. Now, holding the compass in both hands, place the eye at the peep hole in the rear sight vane. Look through the two sights toward B, at the same time damping the compass card by pressing the stop just under the front sight vane. You will now see the proper reading in the prism at the same time observing B. In this compass the "index" (line of sights) moves while the circle is fixed. In the box compass the index (needle) is fixed while the graduated circle moves with the sighting line.

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238. *To Plot an Angle with the Protractor,* lay it along the meridian through the plotted position of the occupied station, the zero at the north, the center of the protractor on the station point. Make a light dot on the paper in extension of the angle read, and draw a line through this point and the station. The protractor is so graduated that it is laid on the east side of the meridian for plotting angles from zero to 180°; from 180° to 360° the protractor is turned over to the left side of the meridian. An arrow drawn on each side of the protractor will assist in rapidly placing it in position with the proper end north. In case the compass is graduated so as to give angles different from the azimuths of a normally graduated compass, mark on the protractor in ink the readings actually given by the compass.

239. *To Locate a Point D,* figure 147, p. 284, *by intersection with compass,* from two plotted points A and X, is accomplished by reading the azimuths of the unknown point from A and X, and protracting the readings from *a* and *x*. The intersection of these two lines is *d* on the sheet.*

240. *A Point Z, figure 147, may be Located by Resection on Two Plotted and Visible Points C and K, with compass and protractor* as follows: At Z read the azimuth to K and to C. Then lay the

*In all discussions of the ground and its corresponding map or sketch CAPITAL LETTERS are used to refer to points on the ground, and small *italicized letters* to points on the sketch. For example, figure 148, p. 284,A is a point on the ground and *a* is the corresponding point on the sketch.

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protractor on the meridian through *k*, and plot the reverse azimuth, that is the difference between 180° and the azimuth Z K. Similarly plot *c z* from *c;* the intersection of the two lines locates *z* on the sheet. The protractor method has one advantage in that the Board need not be oriented before making observations along the traverse or for intersection and resection. The Board must be approximately oriented, however, for sketching in details. Before going out to work, meridians should be ruled at ½ inch intervals over the sheet, as it is difficult to draw parallel lines rapidly in the field. Except for the above differences noted in making locations, the compass and protractor method is the same as the plane table method.†

†**The Advantages of the Plane Table Method are so many as compared with the compass and protractor method, that all sketchers are strongly advised to adopt the former.**

Some Advantages of the Plane Table Method:

1. Once the board is oriented, it is difficult to get an incorrect sight because the ray is drawn while the ruler points toward the object.

2. It teaches the necessity of keeping the sketch constantly oriented, which is a most valuable habit in map reading as well as in sketching.

3. Greater rapidity is possible because of the smaller number and greater simplicity of sketching appliances.

4. By its use far greater skill is acquired in mastering ground forms and in learning to estimate directions.

5. **In using a compass and protractor, the following errors are liable to occur:** (a) Incorrect angle reading due to failure of compass needle (or card of prismatic type) to settle correctly; (b) failure to read the angle correctly; (c) failure to plot the angle read; (d) failure to adjust correctly the protractor on the meridian and the station point; (e) errors due to local attraction (see par. 62) which can be thrown out in the plane table method by back sight orientation.

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INSTRUMENTS REQUIRED IN POSITION AND OUTPOST SKETCHING AND THE METHODS OF USING THEM.

241. 1. *Drawing Board with attached compass or declinator,* figure 135, supported on an improvised tripod or camera tripod.

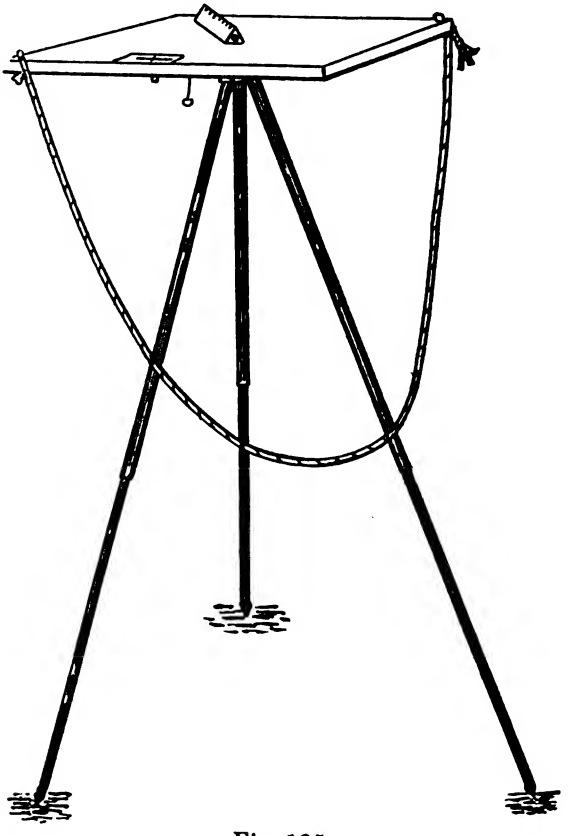

Fig. 135

2. *Loose Ruler,* figure 137, p. 243, with scale of hundreds of yards, scale of sketcher's strides, and scale of map distances, figure 136.

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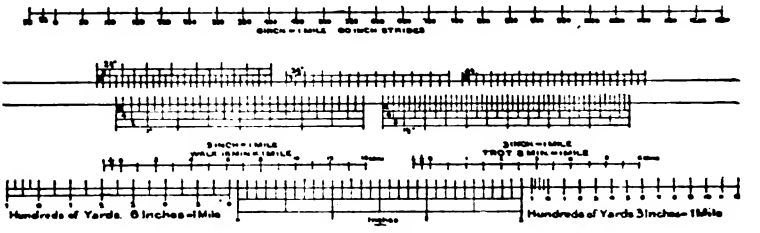

Fig. 136

3. *A Slope or Elevation Instrument*: (a) Service clinometer, figure 138, or (b) Abney clinometer, figure 140; or (c) slope board, figure 137; or (d) Aneroid Barometer figure 141, p. 249, or (e) Hand Level, figure 142, p. 251.

4. *Field Glasses.* (Useful for distinguishing distant points).

5. *Tally Register,* figure 130.

242. *The Drawing Board* should preferably be about 13x14 inches, with a trough compass set in a front edge. There is thus available a drawing surface of about 13x13 inches, which allows four square miles of position sketch to be made with enough extra space to secure the paper to the board.*

Having a board of this size obviates the necessity of orienting it in any special position to get the area on the sheet. *A tripod* may be quickly made of three sticks about four feet long lashed together a foot from the top. A light folding camera tripod, figure 135, arranged to clamp in any position is very satisfactory. This tripod telescopes

*Since the above was written the U. S. Engineer Department has adopted these Boards made according to plans of the author.

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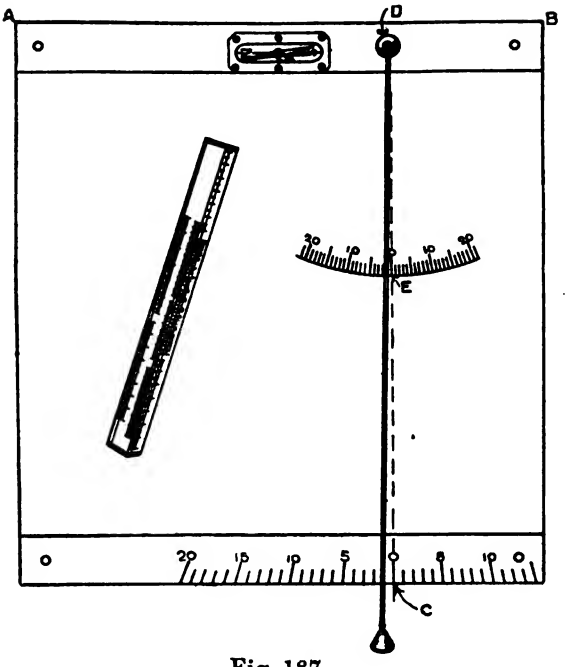

Fig. 137

from a length of 4 feet to 13 inches and is convenient for both road and position sketches.*

An ordinary box compass may be secured to the board instead of the declinator. The compass can be easily attached by screwing it to a piece of cigar box top or a piece of brass, and then screwing this to the back of the board with the compass projecting.

243. *The Loose Ruler* furnishes a well defined sighting line and carries all the scales required in the work of sketching. It is made of a triangular straight-edged piece of wood, with a hole in each

*For sale by Photographic Supply Dealers for $2.00.

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end ⅜ inch diameter x 2 inches deep, filled with lead to give weight to the ruler so that it will remain fixed in position while lines are drawn by its side. On this ruler is pasted a sheet of paper, figure 136, containing scales of hundreds of yards, map distances, and inches. On one blank face the sketcher draws his scale of strides; and on another those of walk and trot of his horse, as shown in the figure. The M. D.'s and scales in figure 136 are reduced one-half. The ruler has a brass ring in one end for attaching to the sketcher's shirt. A coat of shellac makes the paper water-proof. Rulers complete may be purchased from the Secretary, Army Service Schools, Fort Leavenworth, for 35 cents each, and will be found a valuable aid in rapid sketching. For sighting up and down steep slopes a vertical pin stuck in the top of the ruler at each end gives a good line of sight.

244. (a) *The Service Clinometer,* figures 138 and 139, consists of a pendulum B, with an attached

Fig. 138

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arc graduated in degrees and half degrees rotating about the pivot N, and a mirror H, all in a brass case. In figure 139 the front of the case is re-

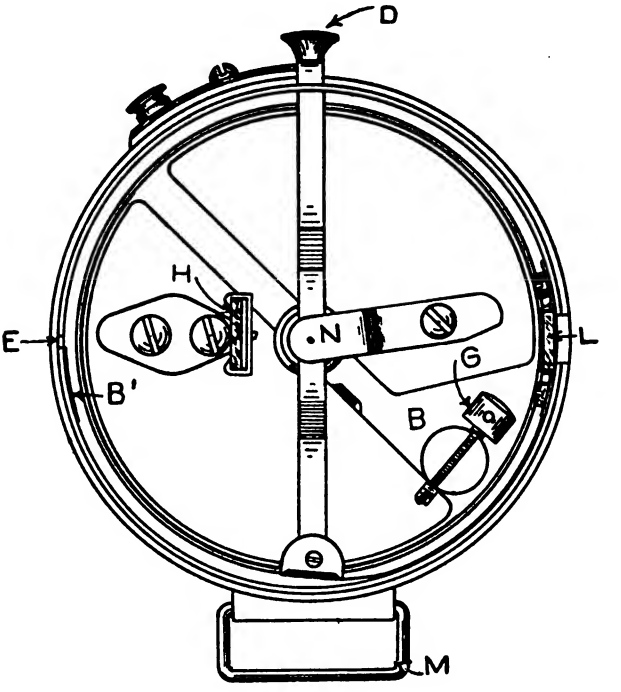

Fig. 139

moved. The observer sights the object through the peep-hole (E) and L, at the same time seeing the scale of degrees inside the rim at B′ reflected in the mirror H. The pendulum is allowed to swing freely by first sliding back the bar and pressing the stop D. The reading is taken when the pendulum comes to rest and the desired spot is at the same time sighted. *The pendulum should not be stopped to take the reading as this displaces the scale.* By

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holding the clinometer so that the zero of the scale is in the center of L, a good hand level is thus secured.

245. *To Test the Service Clinometer.*—Hold the clinometer, stop uppermost, against a post A, with E L, figure 139, on a level with its top and sight the top of a second post, B, 50 or 60 feeet distant. Suppose the angle read is minus 3 degrees. Similarly sight the top of post A from B. Suppose this reading is plus 2 degrees. Add the two readings and divide the sum by 2. The correct slope from A to B is then

$$\frac{-3+2}{2}=\frac{-5}{2}=-2\tfrac{1}{2} \text{ degrees.}$$

The clinometer gives minus readings too large and plus readings too small by ½ degree. This error may be corrected by screwing G to change the center of gravity of the pendulum; or every minus reading must be decreased and every plus reading increased ½ degree. Before starting each day's work, the correction to be made should be written on a corner of the drawing sheet thus: *Decrease minus (down) readings by ½ degree; increase plus (up) readings by ½ degree.* In using this clinometer, its flat sides should be held exactly vertical, preferably against some fixed object; and, *on completing the readings at any station, the sliding bar should be forced under the stop D to lock the pendulum.* This clinometer is one of the best types of hand instruments available for measuring slopes, but must be handled with care to prevent its being

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thrown out of adjustment. Its adjustment should be tested before each day's work.

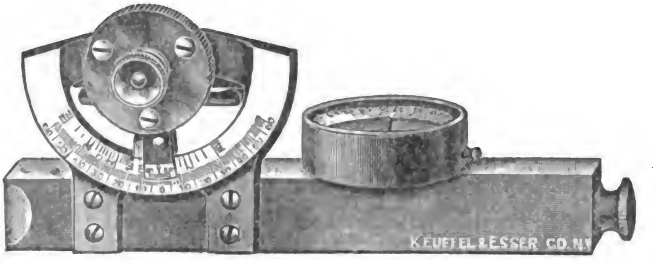

Fig. 140

246. (b) *The Abney Clinometer,* figure 140, consists of a sight tube, with a graduated arc and a level tube with index arm attached. Under the center of the level tube is an opening in the sight tube just above a mirror, in which the image of the bubble is seen by the observer as he sights the object. The bubble is placed in the center of its tube by turning the index arm until the bubble appears to be bisected by the horizontal wire across the end of the sighting tube. The reading of the index on the arc, when the bubble is at the center, is the slope of the axis of the tube with the horizontal. The bubble should be in the center of its tube when the reading of the index is zero and the tube level.

247. *To test* this, lay the clinometer on a smooth topped nearly level post. Draw lines around the four edges of the sighting tube, and read the slopes of this position of the tube. Reverse the clinometer within these marks end for end and read the slope. These two readings should be equal in

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amount, one plus, the other minus. If they are different, add the two readings, divide the sum by 2 and set the vernier at the result on the *same side* of the zero as the last reading. By means of the adjusting screws, bring the bubble to the center of the tube.

248. (c) *A slope board,* figure 137, is a device consisting of a plumb line and graduated arc placed on a drawing board for measuring angles of slope. When a point is sighted along the edge AB, the plumb line makes the same angle with the perpendicular DC, that AB makes with the horizontal, and, therefore, gives the angle of slope. Such a slope board may be constructed as follows: Lay off a perpendicular to AB along the line CD, and on it take DE=5.73 inches. Describe a semi-circle with this radius and lay off from E toward A and B successive distances of one-tenth inch along the arc. These are degrees from CD, because one degree in a circle of 5.73 inch radius gives a chord of one-tenth inch. These degree marks are extended to the edge of the drawing board with a ruler, as shown in the figure. To read slopes, attach a plumb line at D, sight the object along AB, holding the front of the board vertical. When the plumb line comes to rest, press the string against the edge of the board with the finger and read the angle marked. The result should be correct within one-half degree on still days; but if the wind is blowing, good readings cannot be secured. The slope board is easily made and is valuable for a sketcher who has no good clinometer.

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With a slope board, estimates can be checked until the different slopes are learned. It is also useful for reading slopes of hills in profile, that is from a position off the hill from which a good view along the water shed is possible. To do this hold the board parallel to the front of your body, with the lower edge parallel to the slope of the hill, at the same time noting the angle marked by the plumb line. The Abney clinometer can be used

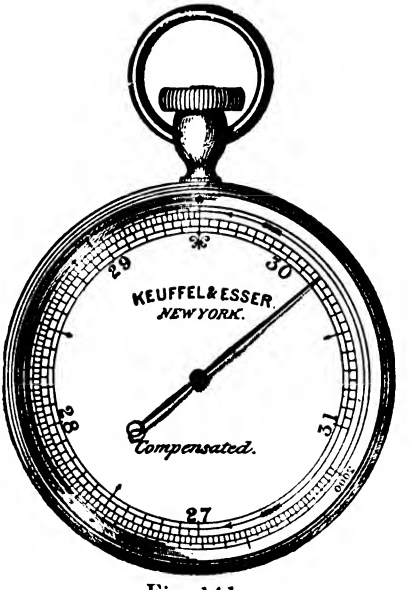

Fig. 141

in the same way. This method is particularly useful in reading the slopes of hills so convex that a view directly down the water shed can not be obtained.

249. *The Aneroid Barometer,* figure 141, has a scale of elevations in feet and a scale of heights of

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a mercury column in inches on its face. The scale of feet is adjustable so that it may be set at the elevation of any known point. The aneroid barometer measures the pressure of the air, and since this pressure is usually changing, the elevation of any point would not be read the same on the scale at different times. This change, due to changing air pressure, is not over 20 feet per hour in fairly settled weather. If, therefore, the sketcher sets the scale of feet at the known, or previously found, elevation of a station *immediately before moving to another,* the error in the determined elevation of the second station would be that due to the change of air pressure in the few minutes required to go this distance, probably less than 5 or 10 feet. This constant resetting of the scale may be avoided by reading the barometer just before starting and immediately on stopping, to get the *difference* of the two elevations. The barometer should only be used thus in finding the successive differences of elevations from station to station. The results obtained with the barometer as above described are sufficiently accurate for military sketches because of the very gradual distribution of the error over the entire sketch. There are conditions of air, however, in which the barometer readings are changing too rapidly for use, and therefore the sketcher must be able to proceed with the sketch, using other methods for determining elevations.

The barometer should be carried in an inner pocket to keep it at as uniform temperature as possible.

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The readings should always be taken with the barometer held in a uniform manner. The best method is to hold it vertical by its ring about 2 feet from the face during the reading. The face of the barometer should be lightly tapped two or three times with pencil or finger nail to prevent the pointer from sticking. The rate of change of the barometer should be tested every 15 minutes for about an hour before starting to work to find if the weather conditions are sufficiently uniform to admit of its use.

Fig. 142

250. (e) *The Hand Level,* figure 142, has a sight tube similar to that of the Abney Clinometer. It has the great advantage that it practically can not get out of adjustment. It is a valuable sketching instrument for determining a horizontal line, and with degrees etched on the object glass vertical angles can be read rapidly and accurately.

THE ESTIMATION OF SLOPES.

251. The ability to estimate correctly the general slope between two points is important for accurate contouring. It is best learned with the transit and stadia as described, par. 234. The sketcher should also have a carefully adjusted clinometer, see par. 245, preferably of the Service type, and make a systematic series of estimates of slopes over

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various kinds of ground, verifying each estimate with a careful clinometer reading. The Abney Clinometer or Slope Board may be used if the Service Clinometer is not available. In reading a slope with a clinometer, the sketcher should sight some *definite object,* as a tree, at a point above the ground equal to the height of his eye, to get a line parallel to the surface of the ground. Some sketchers in reading an important slope take a prone position and sight just off the ground at the desired point, thus getting more accurately the height from the ground of the point to be sighted. The prone position also gives a steadier position for the clinometer, unless it can be rested against a post or tree.

In determining slopes by clinometer reading or estimation the habit should be formed of considering the slope from one definite point to another on the ground, and not simply from one locality to another. If no clinometer is available, a slope board should be constructed, see par. 248, and the estimate of the slope checked with careful readings. The slope board should be used for this purpose only on still days, when good readings are possible.

252. Both horizontal and vertical angles may be estimated with considerable accuracy by determining the number of degrees subtended by the sketcher's hand or finger held at arm's length from the eye. The average angle thus subtended by the hand is about $8\frac{1}{2}°$, but its exact value must be found by each sketcher for himself. The arm is extended full length in prolongation of the shoulder (rath-

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er than to the front so that the distance from eye to hand will be constant), palm up for horizontal and to the front for vertical angles, fingers perpendicular to the palm. The sketcher takes position about 20 or 30 feet from one of the walls of the room and locates the point on the floor, above which his eye comes, when looking past his shoulder and hand held as described. He notes on a rod, or other foot and tenths graduation, against the wall the points visible past the middle joints of the first and fourth fingers. A transit (or box compass) is placed above the point on the floor over which the eye was located, and the angle between the two marked points is read. Similarly, the angle for one, two and three finger widths may be determined. Horizontal angles can be quite closely estimated by laying off successive "hands" between the two points considered, being careful to rotate the body so that the arm will always be in the extension of the shoulder.

253. Instead of thus using the hand at arm's length, the sketcher may similarly determine the angle subtended by one, two inches, etc., held at the fixed distance of 28.6 inches from the eye. Mark on a string a 28.6 inch length; hold the sketching ruler at one end and the eye at the other end of the string; then one inch on the ruler thus held subtends an angle of 2°.

254. *To estimate vertical angles,* the sketcher must learn to *trace a contour*—that is, to be able to place the hand or ruler in the horizontal plane of

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the eye. To do this, mark a number of points around the room at the exact height of the eye. Practice sweeping an arc with the arm at such height that the sight over the finger passes through the marked points. Note carefully the position of the arm during these exercises, and in a short time a very accurate horizontal can be thus marked. This practice is of assistance in noting the position of contours, in determining a reference plane from which to estimate vertical angles and differences of elevations, and in marking points of equal elevation forward on a traverse.

255. After considerable practice it will be possible for the sketcher to estimate slopes with sufficient accuracy by simple observation of their general appearance. Similarly the sketcher soon learns *to trace the contour on which he is standing,* and the position of those above and below it by noting the slope of the ground at various critical points. For example, having estimated the location of the 840 contour from K (Figure 148, p. 284), the 850, 830, etc., are drawn in by eye to show a $2\frac{1}{4}$ degree slope along *r q,* a $1\frac{1}{2}$ degree at *h,* etc., with proper attention to the character of the intermediate ground.

If the sketcher can secure an accurate map made on the normal scale system it will increase his ability in estimating slopes as well as map distances corresponding thereto, to go into the field and *make careful estimates and check them from the map.*

256. *A mistake often made* by sketchers is to

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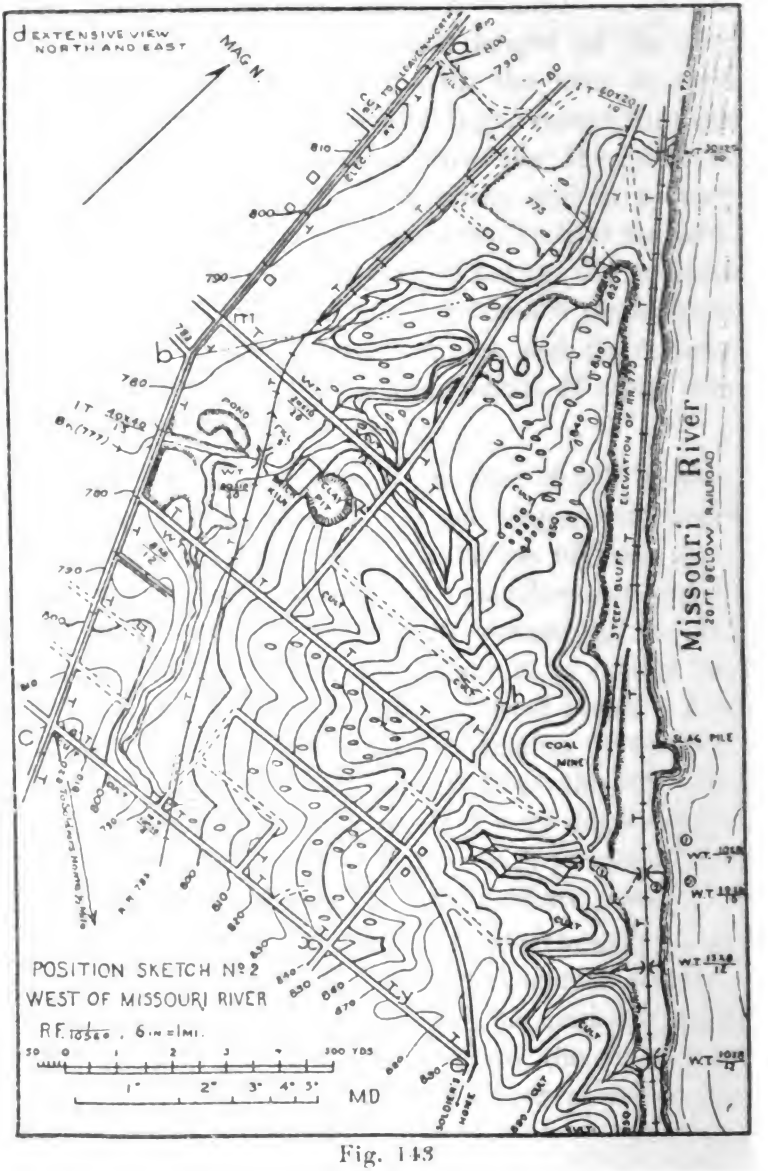

Fig. 143

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estimate slopes, distances and elevations, before they have a definite idea of these units. Such estimates are but guesses and are fatal to good sketching. It is equally incorrect to suppose that all proper estimates are only guesses, because it has been repeatedly demonstrated by student officers at the Service Schools that rapid sketches, which equal or even surpass careful surveys in the graphic representation of ground, can be made without slope or elevation measuring instruments.

The sketch, figure 143, is an exact reproduction of a position sketch made in eight hours by a student officer* of the School of the Line. It is a more accurate map than that made by a previous survey of the same area in which controlling distances and elevations were measured instrumentally,—both in detail and in contouring and it is equally as correct as to horizontal distances and elevations.

THE ESTIMATION OF DIFFERENCES OF ELEVATION.

257. *The ability to estimate accurately differences of elevation* is of the greatest value in rapid contouring, because these direct estimates of elevation are found to be more nearly correct than the elevations determined by estimation of slope and distance. Elevations found from slope and distance are affected by errors in both slope and distance. If the slope is correct, but the distance too great, then the map distance (M. D.) for the slope is contained too many times in the plotted distance, giving too great an elevation.

*Captain Manus McCloskey, U. S. Field Artillery.

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258. *Method of Making Estimates of Elevations.*—Having first learned to determine a horizontal plane (using hand level, clinometer or extended arm) the elevation of the unknown point above or below this plane is estimated by comparison with the heights of objects in the vicinity, such as telegraph and telephone poles, trees, horizontal lines on buildings and bridges (copings, window sills, etc.). The height of main line telephone or telegraph poles is usually 25 or 32 feet; of street railway poles about 25 feet; trees in a full grown orchard 15 to 20 feet; full grown oak trees 40 to 75 feet; the height of an ordinary story of a brick house (window sill to window sill) 10 feet. The sketcher should learn the height of such familiar objects in the vicinity of his station. In estimating the height of any object to be used as a reference, it is well to *keep in mind a well known value such as 10 feet* and imagine this applied successively to the object.

Suppose the sketcher is standing on a hill, looking in the direction of the traverse, across a valley toward another hill. He makes a careful estimate of the point (or locates it through his hand level) at which a horizontal plane strikes the hill across the valley. Then by observing the position of the bottom of the valley with reference to this plane, the sketcher estimates the difference of elevation as so many telegraph poles, etc., below the plane. The result should never be out more than one-half contour interval. The best method of checking these estimates, except by the use of transit and

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stadia, par. 234, is to *consult an accurate map* after making the estimate and see the difference in elevation shown.

259. By *carrying forward with long sights,* (using hand level or clinometer at zero), points of equal elevation along a traverse, elevations throughout a day's road sketch can be obtained with sufficient accuracy. Another assistance in carrying elevations and in securing correct contouring, is the *uniform slope of streams.* The surface of a large river is practically horizontal so far as the requirements of a day's sketch are concerned. The Missouri river for instance, has a surface slope of only 6 inches per mile, or only $7\frac{1}{2}$ feet in 15 miles of length. Hence wherever the sketch approaches the river, there is furnished a reference for elevations. The same principle is true of smaller streams, which usually, over considerable length, have a practically uniform rise, as 10, 20, etc. feet per mile. Having determined this rise, the elevation of each crossing of the stream is thus known. Often in sedimentary formations, an *outcrop of rock* will always occur at the same elevation. The sketcher must learn to observe all topographical features and make use of them in his estimates.

MILITARY SKETCHES SHOULD SHOW:

260. *All lines of communication*: Roads, trails, railroads (with towns to which they lead, and railroad stations); rivers, lakes, canals, telegraph and telephone lines.

All objects giving cover or forming obstacles:

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Woods, tall growths of grain, swamps, unfordable bodies of water, ravines, rugged cliffs, stone walls, fences, hedges, cuts and fills.

The configuration of the ground: Contours showing all hills in their true location and shape; the character of their slopes and their relative heights; all ravines and slight undulations affording a sheltered line of movement to troops.

All easily distinguished landmarks: Isolated trees of unusual type such as lombardy poplars; houses, especially those of stone and those at cross roads; villages and towns to show the general plan of streets and houses.

All military dispositions: Defensive works (trenches, saps, etc.); bodies of troops drawn to scale.

All forms of constructed obstacles and demolitions, as wire entanglements, mines, etc.

The vulnerable points of lines of communication: Bridges, culverts, locks and dams, ferries and fords, with the character of each.

All stores and supplies for men and animals: Water supply, grazing grounds, storehouses of grain, etc.

A title, giving the locality sketched, the sketcher's name, a scale of yards, the R. F., a scale of M. D.'s, and the magnetic meridian.

262. Figures 144 and 145 show the *conventional signs prescribed in Field Service Regulations* for field sketches. Fig. 18, p. 42, Map Reading, shows additional signs for maps, but the sketcher in mak-

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ing a topographical reconnaissance will rarely have sufficient time to fill his sketch with symbols, and equal clearness, with much greater rapidity of execu-

'The following abbreviations are authorized for use on field maps and sketches. When these words are used they must be written in full or abbreviated as shown. The abbreviations must not be used for other words than those in the table. Words not in the table are not as a rule abbreviated.

abut.	abutment	P.O.	post Office
B.S.	blacksmith shop	Pt.	point
bot	bottom	Q.	quarry
Cr.	creek	q.p.	queen post
cul.	culvert	R.	river
E.	east	R.H.	round house
f	fordable	R.R.	railroad
gir	girder	S.	south
G.M.	grist mill	s.	steel
i.	iron	S.H.	school house
I.	island	S.M.	saw mill
Jc.	junction	Sta.	station
k.p.	king post	st.	stone
L.	lake	str.	stream
Mt.	mountain	tres.	trestle
N.	north	tr.	truss
n.f.	not fordable	W.T.	water tank
p.	pier	W.W.	water works
pk.	plank	W.	west
		w.	wood

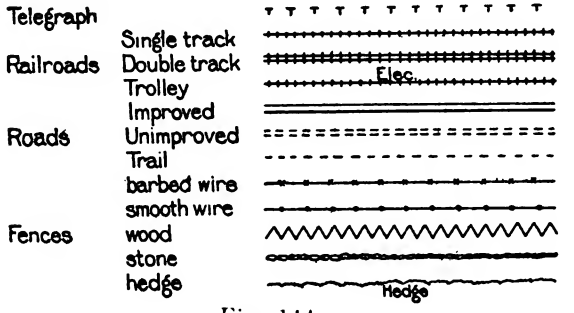

Fig. 144

*The sign for hedge given above is not as satisfactory as that shown in figure 147, p. 284, along the west edge of the sketch. The symbols for wire fences and telegraph and telephone lines along roads should be placed on the lines used to mark the roads.

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tion will often be secured by printing in small capitals the name of the growth in a given enclosure, as CORN, WHEAT, CULT. (for cultivated). In the same manner, with marginal notes and simple drawings, the character and condition of roads, ferries, bridg-

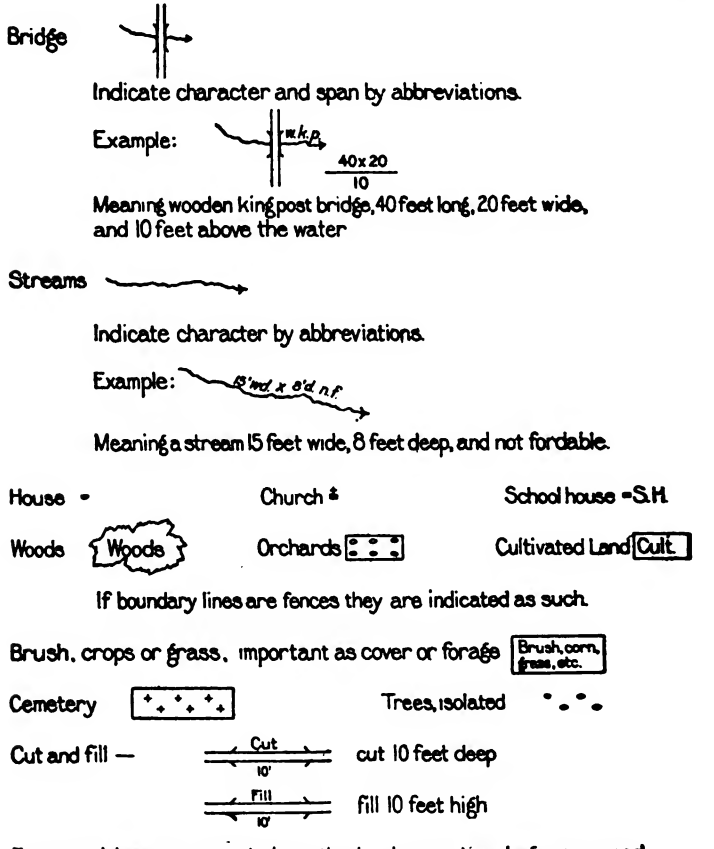

Fig. 145

All lettering on Position, Road and Place Sketches, except names of streams and roads, should be made so as to be read facing north. The lettering on Outpost sketches is to be read facing toward the enemy.

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es, fords, buildings, etc., should be described; the sketch should be amplified by a *Reconnaissance Report* of the terrain, where conditions make it necessary, see par. 312. Points from which exceptionally extended views are obtainable should be marked in the margin, see reference to *d,* figure 143.

Prominent ridges, commanding positions, church spires, towns, etc., when visible, should have their direction marked by an arrow, with their approximate distance marked on it (see figure 143, to Soldiers' Home from *C*) even when several miles distant.

263. Sketches should be made on *tracing paper,* in firm pencil lines using a soft black pencil (HB), so that blue prints may be made directly from the sketch without the waste of time and labor of tracing. Since a number of copies of almost every military sketch must be made in the shortest possible time, they should never be finished on heavy drawing paper (except in the early practice work) nor in colors, unless copies of the original are not desired. In combined sketching, the work of all the sketchers should be uniform as to heaviness of lines and size of conventional signs. In case colors are used, the following system should be followed: Yellow for roads; green for trees; blue for water; red for stone structures; brown for contours and wooden structures. On the finished sketch, as intended for issue (whether blue print or original drawing), colors may be used with added clearness.

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264. In making a military sketch the important considerations are *clearness, accuracy* sufficient for all military requirements, *simplicity* and the *completed sketch* in the time available.

Only details of military importance should be shown. Objects which are valuable from a tactical standpoint should be constantly kept in mind. It is of far greater importance to show location, shape and character of a wooded area by drawing its outline of conventional signs, within which is written its character, than to carefully fill up an area of incorrect size and shape with symbols for woods. Information of a wide dead space formed by a convex slope in front of a proposed defensive line is more important to the commander than the exact height of the position; therefore care should be used in spacing contours to show the ground as it really exists.

Under service conditions, the *importance of finishing the entire assigned area* in the allotted time can hardly be overestimated; but in learning to sketch, accuracy and clearness should be the only considerations. The sketcher should, therefore, in his early sketches, *measure every distance, slope* and *elevation,* after making in each case careful estimates; and he should only begin to depend on his estimates when positive that they are sufficiently accurate.

Distances to individual points off the main control lines (traverse or triangulation) should not be in error more than fifteen per cent; plainly visible

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slopes should be correct to within one degree; differences of elevation, within one contour at distances up to five hundred yards from the traverse. In case the sketcher has had a course of surveying with precise instruments as described in *Part II,* he should be able, on its completion, to estimate distances, slopes, and elevations so accurately that he may dispense with many of the measurements to points off the main control lines after his fourth or fifth sketch. It is well for the sketcher to bear in mind that *on the principal control lines accuracy is of first importance,* but in locating any single point from which no other points are determined, its general position relative to the remainder of the sketch is sufficient. Rapidity is gained at the expense of accuracy in some parts of the work, and the difference between a fair and an excellent sketch depends much on the correct choice of the part of the sketch where accuracy is paramount and where it is unimportant. The balancing of accuracy and rapidity is taken up in detail under Position and Road Sketching; but *in the first sketches accuracy is everything.*

CLASSIFICATION OF MILITARY SKETCHES.

265. Military sketches are classified as *individual* or *combined* sketches. An individual sketch is of limited extent, executed by one person. A combined sketch is the result of the simultaneous work of a number of sketchers, so combined as to make a map covering a number of parallel roads (Combined Road Sketch), or an area extending across the

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front of the command (Combined Position Sketch).

Military sketches are also classified according to their object or the method of their execution as:

1. *Area Sketches,* which are of three kinds (a) *Position,* (b) *Outpost,* (c) *Place Sketches.*

2. *Road Sketches.*

A *Position Sketch* is one of a military position, camp site, etc., made by a sketcher who has access to all parts of the area to be sketched.

An *Outpost Sketch,* as its name indicates, shows the military features of ground along the friendly outpost line and as far toward the hostile position as may be sketched from the rear of and along the line of observation.

A *Place Sketch* is one of an area, made by a sketcher from one point of observation. Such a sketch may cover ground in front of an outpost line, or it may serve to extend toward the enemy a position or road sketch from the farthest point which can be reached by the sketcher.

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CHAPTER III.

METHODS OF SKETCHING.

266. *The Location of Critical Points.* Having learned the uses of military sketches and the details to be represented, it is next in order to take up the methods used for determining the location of the necessary critical points, around which the features themselves are sketched.*

Every critical point desired must be determined: (1) *Horizontally,* that is its horizontal distance and its horizontal angle of direction (azimuth) from the north-south line must be found, with reference to a starting point, assumed or known; (2) *Vertically,* either by finding its difference of elevation directly or by determining this difference of elevation from the slope and distance to the desired point with reference to the known point. A beginner finds it much simpler to become thoroughly familiar with the making of horizontal locations, before attempting the vertical locations, from which contours showing the slope of the ground are determined. For this reason contouring is taken up after the description of plotting in the horizontal details; and the beginner should practice making horizontal traverses, and triangulations, and drawing

*A critical point is one at which there is an abrupt change of general slope, or an abrupt change of horizontal direction.

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details such as roads, woods, buildings, streams, before he attempts a contoured sketch.

267. *The Horizontal Location of a Point may be determined either by*:

(1) *Traverse,* or
(2) *Intersection,* or
(3) *Resection,* or
(4) *Offset,* or
(5) *By estimation* of distance and measurement, or estimation, of direction.

268. 1. *The location of an unknown point,* as B, with respect to a known point, as A, *by traversing.*

The drawing board, figure 135, p. 245, is set up at A, figure 147, p. 284, and levelled as accurately as possible by eye. The board is then *oriented* by rotating it horizontally until the magnetic needle of the attached compass points north. At every station the board must have this same angular position, so that *every line on the sketch will always* be parallel to the corresponding line on the ground. Assuming a point *a* on the paper in such a position that the ground to be sketched will fall on the sheet, lay the ruler on the board and point it toward B all the while keeping the edge of the ruler on the point *a.* Draw an indefinite line along the ruler's edge from *a* toward *b.* Now walk to B, counting strides and keeping a record of them with a tally register, par. 229. With the scale of the sketcher's strides on the ruler, lay off the number of strides found from A to B and mark the point *b.* Other

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points, as C, F, etc., would be located in the same manner.

269. 2. *The Location of an Unknown Point,* as K, with respect to two known and plotted points, as T and C, figure 147, *by intersection.*

Set up, level, and orient drawing board at T, by laying the ruler along the line *t c* and rotating the board horizontally until the ruler points exactly toward C. (This is called *orientation by back sight,* as opposed to that described at station A, which is *orientation with the needle.*

Lay the ruler on the board, sight and draw a ray toward K. This ray need not be drawn entirely up to *t,* but only for a short length at the estimated distance to scale of K from T. Now move to C, assumed to be already plotted on the sheet in *c,* and having set up, levelled and oriented by a back sight to T, sight toward K, as done from T. The intersection of these two rays locates K on the sheet at *k.* Having *c* and *k* thus located, they may be used in the same manner for determining other points by intersection. It is seen from the above that a point is located by intersection without the sketcher's going to that point. To locate a point by *resection* the board must be set up on the ground at the point whose position on the sketch is desired.

270. 3. *The Location of a Point by Resection.* 1st Method. Having given a direction line, as *c q* figure 147, p. 284, on which lies the desired point, and a plotted point, as *k,* outside of that line; to determine the position on the sketch of any point

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on the line C Q, as Z: Set up, and level the board at Z, then orient by laying the ruler on *c q* and rotating the board until the ruler points at C. Clamp the board in this position. Pivot the ruler about a wax headed needle stuck at *k* and sight K. Draw a ray along the ruler and its intersection with the line *c q* locates *Z* on the sketch at *z*. This method is as accurate as the method of intersection because of the exact orientation secured by back sight on C.

2d Method. Having given two plotted points, as *t* and *c*, fig. 147, to determine the position on the sketch, *k*, of a point K on the ground. Set up, and level the table at K, orienting with the needle. Clamp the board. Pivot the alidade on *t*, at the same time sighting T, and draw a ray along the ruler toward your body at the estimated position of *k*. Similarly, pivot the alidade on *c* sighting C, drawing a ray until it cuts the one from *t* and this point of intersection is the required point *k*. ***This method*** is available as soon as two visible points are plotted, and *finds very frequent use in sketching in details around a point such as K, which is not to be used to extend the triangulation.* Both of these two methods are of great value in position sketching. The 3d and 4th Methods of resection, par. 155, *Part II*, may also be used, but they will only be advisable in rare instances.

271. 4. *The Location of Points by Offset.* This consists in measuring distances perpendicular to the traverse for locating details. For example, a winding road Z L might be located by sighting

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from Z towards L and drawing the ray *z l*, figure 147. The distance from Z to L is then measured along the ray (or along the road itself) and the critical points 3, 4 and 5 located by offsets perpendicular to the ray. The most general use of this method is in locating details along a traverse where the offsets are made by estimation.

272. *Methods in detail of finding the elevation of an unknown point* D *from a known point* A, figure 148, p. 284, *and the location of contours on this line.*

1. *Measure the slope* from A to D with clinometer, or slope board, *and the horizontal distance* by traversing, intersection or resection. Plot to scale the distance found and apply the M. D. for this slope successively along the plotted length. The number of times the M. D. is applied, multiplied by the contour interval (V. I.) equals the difference of elevation between A and D. For example, suppose A, figure 148, is at elevation 800; distance *a* to *d* as plotted 2.5 inches; V. I.=10 feet; slope from A to D=+1½°. The M. D. for 1½° is found to be contained 5¾ times between *a* and *d;* 5¾×10= 57.5 feet. D is therefore at elevation 800+57.5= 857.5. Now looking at the ground along A D, you find it to be a slightly concave (hollowed out) slope north of the bridge and steeper near the top. There are to be placed in the space *a d* contours 800 (at *a*), 810, 820, etc. to 850; they would be spaced close together at the top and farther apart towards the bottom in order to give a true representation of the

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slope. South of the bridge (1) the ground is level and consequently no contours appear here.

In rare cases only do the slopes of hills change so suddenly at any one point that the actual condition of slope can be shown by a mechanically exact interpolation of contours by the application of the scale of M. D.'s. above or below this point of change. Suppose, however, such a case does exist as shown between *x and e* at *y*, figure 143, p. 255. This condition could be shown only by reading the slope and measuring the distance from X to Y and from Y to E. *x y* and *y e* could then be plotted to scale and the 6 degree contours spaced uniformly along *x y*, using the scale of M. D.'s. This assumes that the point of change of slope Y on the ground can be exactly located, but in reality *there is always more or less uncertainty as to the exact point at which the change takes place.* Moreover, it is exceptional to find ground sloping exactly uniformly as X Y. The usual case is either a convex or concave slope, changing so gradually from point to point that the observer can not pick out the exact points of change, much less be able to mechanically show these points by contours. He can however represent by contours the general character of the slope accurately by contours properly spaced.

In the older text books a laborious method of contouring was prescribed in which the sketcher would pace along a slope to each point of change and plot the contours on these portions. This method is impossible for rapid sketching on account of

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its slowness and is moreover inaccurate on account of the accumulation of errors due to frequent short readings to unimportant points.

In military sketching the essential feature sought in contouring is to convey to the reader of the sketch a correct representation of the ground as it appeared to the eye of the sketcher. The sketcher can only give this information by determining the difference of elevation between two definite points, at the top and bottom of the line, and then, knowing the number of contours required, *spacing them to show the variations of slope as they appear to him.* For this reason great stress has been laid on the necessity of acquiring by diligent practice the ability to estimate the map distance corresponding to each degree of slope usually met with.

2d Method—Measure the difference of elevation directly with the barometer, and space the contours required by this determined difference of elevation to show the actual slope of the ground.

Method of Contouring After Acquiring Skill in Estimating Distances, Elevations and Slopes.

273. 1. *Estimate the difference of elevation* between A and D, Fig. 148, and, *space the contours by eye.* Or the number of contour intervals between A and D may be estimated. In this case the number of contours, including the top and bottom ones, is one greater than the number of contour intervals.

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When a Generally Uniform Slope Extends to the Limits of the Sketch.

274. 1. Read the *slope with a clinometer* or slope board, and with the scale of M. D.'s for the slope locate contours to the limits of the sketch without determining the elevation of any point on the line other than the one known.

2. *After skill in estimating is acquired,* estimate the slope and plot the contours with the scale of M. D.'s.

3. *After skill in plotting by estimation of the Map Distances corresponding to different slopes is acquired,* estimate the slope and space the contours by estimation.

THE EXECUTION OF A POSITION SKETCH IN DETAIL.

275. The instruments required by a beginner are preferably the following, but others may be used as noted below:

1. *Drawing Board with Declinator on Tripod,* figure 135, p. 241, see par. 241.

2. *Loose Ruler,* figure 137, with scales described par. 213, figure 136, p. 242.

3. *Service Clinometer,* figure 138, see par. 244, carried in upper right blouse pocket, and secured to it by a strong cord.

4. *Tally Register,* par. 229, attached by a string and carried in the left trousers pocket.

5. *Equipped Pencil, Knife and Ruler Holder,* figure 146. This may be made of heavy canvas sewed over a board frame. It should be secured to

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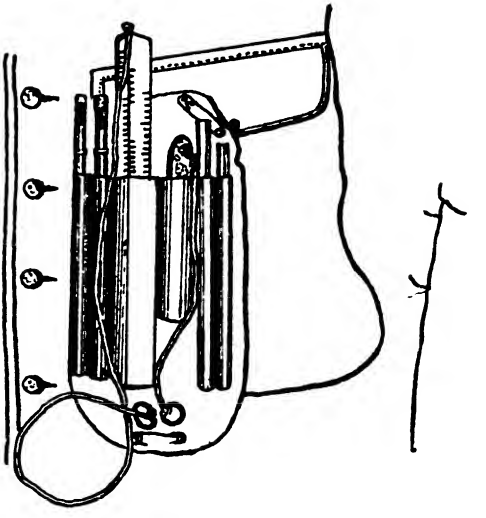

Fig. 146

the sketcher's blouse on his left breast. The knife and ruler may well be fastened to the holder as shown, to prevent their being lost.

It will be of great value to the sketcher to have *one definite place for each article of equipment, and one well fixed method of performing each operation* in sketching so that there may be no hesitation in the work. Sketching utensils have a remarkable habit of losing themselves, unless they are tied to something or placed in some particular receptacle after each use. Pencils of different degrees of hardness should be marked clearly so as to avoid delay in taking out the proper one. The points should be protected by rubbed-tipped brass covers.

6. *A Soft Rubber Eraser* may be carried attached to a cord around the sketcher's neck.

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7. *Field Glasses* are of considerable value in picking out distant points for intersection or resection, and for studying the details of ground forms at a distance. If used they should be carried on a waist belt. It is well to have a reserve of at least one each, of the ruler, rubber eraser, pencils and a sheet of celluloid for use in rain, all carried in a haversack, or dispatch case.

METHODS OF WORK.

276. The detailed methods of using the instruments have been given heretofore. A description will first be given of the methods of locating the horizontal details only, followed by the methods of contouring the area. It will be best for the beginner to pursue this system in his first two or three sketches, of locating and drawing in roads, streams, woods and all other horizontal details, and on this frame-work later locating his contours. To do both simultaneously will at first prove confusing because of the large number of matters to be kept in view. However, both horizontal details and contours can be carried on together from the start if so desired, but no effort should be made to do rapid work until the methods are familiar.

1. *Select and Traverse a Base Line.**

2. *Locate a Series of Critical Points* over the area by Intersection.

3. *Fill in the detail,* par. 260, *in the vicinity of these triangulation points,* see figures 144 and 145,

*It is assumed that you have previously determined your length of stride and have constructed a scale of strides, par. 229.

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p. 260, for conventional signs prescribed by Field Service Regulations for sketches.

4. Fill in detail around other important points located by Resection.

5. Fill in all other required details by Traverse to all necessary points not visible from the Intersection or Resection Stations.

277. The *Base* is a line in the area to be sketched, as centrally located as possible, and from one-fourth to two miles long depending on the size of the area. It should be long enough so that lines drawn from its ends to locate necessary critical points by intersection, will intersect at angles between 30° and 120° to give accurate locations. Its length should generally be not less than one-third as long as the greatest dimension of the area to avoid having to extend small triangles too great a distance from the original base. Often a shorter base can be used if located in the middle of the area than if near one end, because the extension of intersection points would be made on both sides of the base.

The ends of the base should be marked by some well defined objects, such as telegraph poles, trees, corners of buildings, or even temporary poles, branches of trees, weeds, etc., set up by the sketcher so that they may be seen by him from a distance in sighting back on these points. If an object such as a telegraph pole is chosen as an end of the base, so that the board cannot be set up exactly under the point which will later be used to sight back on,

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the sketcher orients his board near the pole and draws a short ray toward it, pacing and plotting its distance, to scale, measured from the board's location. The pole is thus located accurately on the sheet for back sighting purposes though the board is never set up exactly at that point. This method would also be useful where local attraction is known to exist at the desired station point, as in the vicinity of poles carrying heavy electric currents.

An extensive view of the area should be possible from the ends and from several intermediate points of the base. If the area is intersected by ridges and valleys, the best base is usually to be found along a central ridge(because from this position the two adjacent valleys are visible as far as the tops of the two ridges beyond. If the ridges are very flat topped and convex in shape, so as to prevent a good view into the two adjoining valleys, it may be advisable to locate the base perpendicular to the axes of the ridges, though the pacing up and down hill is less accurate. A road or railway crossing the area more or less perpendicular to the ridges and valleys, gives a very good base. The accuracy of pacing the base is of great importance, because errors made in this part of the work extend and accumulate over the entire area. To secure this accuracy, the base should, where possible, be generally level and lie over firm soil such as roads, trails, railroads or pasture land.

In figure 147, p. 284, the broken base A B C, along an edge and extending across the middle, is

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chosen because of the good view obtainable, the good pacing possible along the road and railroad, and the central location afforded. It is started from A because this happens to be the first point of the area reached in going to work; and also because sights to B and to D determine two boundaries of the area. The length of this base is such that triangles with suitable angles of intersection are possible as shown in figure 147. The telegraph poles along B C give good points to resect on. In figure 143, p. 255, the base used was A, B, C, E, because from this line a better view over the area was possible than from any base in the center of the area.

278. *To Traverse the Base.* Set up, level and orient the board at one end of the base, A, figure 147. Draw a meridian on the edge of the sheet parallel to the declinator trough's edge. It is well to form the habit of placing the sheet on the board with an edge parallel to the N-S line of the declinator, so that you can always use this edge and the other parallel edge as meridians. Assume a point *a* on the sheet corresponding to A on the ground. In this sketch a telegraph pole is selected, and the corresponding point on the sketch is taken near the southeast corner of the sheet because the area lies to the north and west.

From the first station, prominent easily distinguishable points are sighted, such as hill tops, stream junctions, stream heads, etc., to begin the

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location of these critical points, by intersection.* In figure 147 sight along road A B and A D and toward the stream junction Y, drawing light indefinite lines (rays) with 4 H pencil towards these points. Traverse from A, noting the number of strides recorded on the tally register opposite the house and the wire fence north of road A B but without halting until B is reached.

279. *Procedure at B.* Halt, set up, and orient the board by a back sight on A. With the scale of strides on ruler, scale off the distance from A to B also from A to house and to wire fence. Now, before the orientation has been disturbed by the work done on the board, pick out with your field glasses the next station, C, an elm tree on top of a railway cut, sight and draw a ray in its direction. Next draw in with H (or HB) pencil the road A B, the house at its estimated distance from the road and sketch the wire fence in the direction it was observed to lie. Take a careful sight at the chimney of Flint House, which is a prominent point visible

*It is well to have a systematic order of taking the intersection sights from any station, as for instance, from right to left across the front, so that no desired object will be overlooked by a haphazard method. These objects sighted should also be recorded systematically so that the different rays will not be confused when the time comes to finish the intersections. This is best accomplished by placing a serial number exactly on each ray from a station; and on the edge of the sheet, placing a tabulated list of these sights for each station as follows:

From Station A—
Sights:
1. Road A D.
2. Wire fence corner.
3. Stream junction.

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from all parts of the area and will be useful as a point to resect on. Traverse toward C, halting at X. On the top of the bank here, set up, orient by a back sight and take the following observations: Flint chimney; bridge north of A; hill top at road A D north of this bridge (north limit of sketch); directly up the ravine line north of X; to the stream junction just east of the railroad track; to Y. Now sketch the Flint House and barn; the wire fence east of X running toward the north and its branch to the road A D; the stream from Y to road A D and trees along it; the three small ravine lines joining this part of the main stream from the south; telegraph line along the railroad right of way toward B; the orchards at Flint and at A.

280. *Traverse toward C,* noting the recorded strides at G and the ridge north of it. Halt and set up at T (south end of bridge). Scale off T, G, etc., from B. Sight on K and along the main stream to the east and west, also up the draw east of C; to intersection of roads A B and L Z also ridge top at M; sketch in the main stream east to Y and the branch ravine lines on this section; the trees and stream banks (shown by hachures or brief statement of condition), and the railroad track back to X. M is at the intersection of the north edge of road A B with the ridge top, and its map representation *m* is at the intersection of *t m* and *a b* prolonged. In the same way, later on, from station K the other critical points (ridges and valleys in this case) on the road are located by drawing rays to intersection

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with *a b* prolonged. It is well here to call attention to the importance of locating all straight lines in the area such as the boundary fence of this road, wire fences, hedges, straight line of telephone poles, etc., because they furnish a valuable means of locating any points on them by intersection as was done in the location of M from T.

Continue the traverse to C, noting number of strides at wire fence corner without halting. At C halt, set up and draw in detail between C and T, also the wire fence east to D. The east end of this fence was found from X by intersection on the line *a d* from the 1st station, A.

It will be observed that you have now located all the horizontal details east of your Base without traversing any of this area, with a great resultant saving of time. All of this work has been done *by traversing* along the Base and locating the necessary critical points east of it *by intersection.* Sight to K to complete its location, also to the point where road Z L crosses stream, and the ravine line junction with the main stream south of C.

281. *Resection at Z.* It is now necessary to carry the work forward from C, but on hill Z there is no definite point which could be located with certainty from T and C by intersection. You therefore look for something to sight on, so as to establish a direction line on which you can place yourself after reaching hill Z. You observe that you can look exactly up a small ravine toward a tree at Q, so draw a ray in this direction. (A well de-

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fined fence corner, bush, etc., would be equally as satisfactory as the ravine to sight on.) Move at once to the top of hill Z and place yourself on the direction line from C, at the most convenient point of the hill for observing the ground (on road Z L). Set up and locate your position by resection on K, and sight the stream junction toward K, also the draw S by estimating its number of yards from Z. Sight along the general direction of road L Z. You observe that a hedge fence extends along the western boundary through Q. You have not located this hedge, but observe that you will be able to do so by intersection from Z and K on two of its points, Q and R. Therefore, sight from Z at these two points on the hedge, then move to K and complete their location. Draw in the hedge R Q, thus locating all the critical points sighted on this line from E. From K locate the critical points on road A B as described above. Draw in all the water course and water shed lines west of the railroad, for which sufficient critical points are now known; also the other details such as roads, trees, houses, wire fences, etc.

282. It will be observed that the horizontal details of this sketch have been put in by use of the methods of *traversing, offsets* (along the base), *intersection* (*d, m, k, q, etc.*), and *resection* (z). S was located by *estimation,* since it was only about 200 yards from Z. A small amount of estimating has been done in getting the directions of ravines and of water sheds of ridges, between the two or

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more points located on them. Gradually you can increase the amount of freehand sketching based on estimation as you acquire skill from practice. The portions of the area located by resection, intersection or traverse will vary in amount for each particular sketch, depending on the nature of the ground, the amount of woods, etc., preventing good views.

It is evident that the work from a carefully paced base over fairly level ground is more accurate than if traverses were run all over the rough and steep parts of the area. Therefore, as much of the work is done by intersection and resection as possible, traversing (except along the base) being done only where desired critical points are hidden by woods, etc.

You will also observe that *all sketching of details has been done toward the rear*—that is, from the last located point back to others previously determined. This is a vital principle in all this work, that *no sketching should be done in front of the last located point.* (Except that local details may well be put in by estimation for 50 to 100 yards forward from each station.) There is with beginners a strong tendency to do this, especially in drawing contours, but such work will usually be incorrect and have to be erased, causing a waste of time and great confusion to the sketcher.

CONTOURING THE POSITION SKETCH.

283. Having thus completed the location of the horizontal details of the area, start in again at A

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to determine the vertical locations—that is, elevations, slopes, and the contours to represent the shape of the ground. Suppose A to be at elevation 800 feet above sea level. On the sketch you now have located the horizontal position of all stream lines, draws (water flow lines), and hill tops, figure 147, *From station A* read carefully the vertical angle ($+1\frac{1}{2}°$) to the top of hill D. Apply the M. D. scale on the ruler to *a d*, and you find that there are 5 contours required, see par. 272, between A and D, the 810, 820, 830, 840 and 850; but reading the angle to the bridge north of A, you find its value is zero degrees, or horizontal. Therefore all five of the contours fall beyond the bridge and you can see that the slope is gently concave. You therefore *space the contours accordingly to show this fact* as in the figure, 148.

284. *Procedure at B.* Next move to B and read the angle to A (—1°), and applying the M. D. scale, you find two contour intervals between A and B the ground is quite steep near B and flat near A. You therefore space the contours as shown in the figure. To verify your idea of how close together to space the 810 and 820 contours, read the slope from B to the foot of the hill. You find it to be (—3°) by applying the M. D. scale; this agrees with the spacing already estimated. While at B note the general slope of the road to the west for use in spacing contours along it later.

Next move to X, set up and read the slope to B (—3°), to Y (—3°), to G (—3°). Applica-

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tion of the scale of M. D., shows that B (820) is $3\frac{3}{4}$ intervals below X. Hence X is at elevation 857. The slope from X to B is practically uniform and the contours are spaced as shown. Applying the M. D. scale, you find $5\frac{1}{2}$ intervals from *x* to *y*. This is a gently convex hill and the contours are drawn as shown. Since X is 7 feet above the 850 contour, this is placed nearly one M. D. distant from *x*; and for a similar reason the 810 contour falls a short distance south of the stream. Join up the contours between the line *x y* and *x b a*, with due regard to intermediate slopes of the ground. Also, having determined the elevation of Y (805), you are able to draw in the contours on the ridge *y d* by examining its slope through your field glasses. Extend these contours to join those already located south of *d*, keeping in mind the variation of the ground and remembering the small map distance corresponding to small inequalities noted.

285. *Estimation.* Instead of reading the slope to the top of Flint hill you observe that it is only 5 or 6 feet higher than X, and hence only one contour (860) goes in; this falls about 50 yards from X, and is drawn in by eye as shown. You also draw in those required between the 850 contour and B along the road.

Now move to T and stop a moment to read the slope up ravine G, without setting up the Board; likewise at the ridge just north of it. Continue to T, set up the Board here and put in contours between X and ravine G, and on ridge to M.

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Read the slope from T to X and find the elevation of T as heretofore described for B and X. From T read the slopes to ridge and valley points on the fence running east to D, and draw in the contours down to the main stream.

Proceed to C; read the vertical angle to X, to K and to stream junctions south of C, locating contours as already explained. Continue over the entire area, always remembering to locate contours in rear of the last known point, and not to leave a station until all the details up to that point are drawn in.

286. *Locating Horizontal Details and Contours Simultaneously*: Having finished locating the contours over your first area, go back again to A and carry on both horizontal and vertical determinations together. This can now be readily done simultaneously on the area you have studied by the two separate operations. For example, at A, set up, orient with the needle, draw a meridian, sight D, B, Y, and fence corner; read vertical angle to D draw in road A D. Move to B, set up, orient by back sight on A, plot *b*, house and wire fence; sight C; draw in road A B (note slight curve), cattle chute and switch; sight Flint House chimney. Now read the vertical angle to A and contour *a b*, and so on continue the work, being careful to follow a regular order in the different steps. It is well to keep in mind, however, that there are really two independent sets of determinations being made at each station, one horizontal

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the other vertical, as this helps to systematize the work.

287. *As you acquire skill in sketching, in estimating and tracing contours, you will constantly require fewer and fewer controlling located points, such as B, X, Y etc., with a corresponding gain of speed and accuracy of representation.*

EXECUTION OF OUTPOST SKETCHES.

288. *The Making of an Outpost Sketch* differs from that of a position sketch in nothing except that in the former the sketcher cannot advance beyond the line of observation, but must show the ground from one-half to two miles in front of this line toward the enemy. Consequently, he will be limited to locations by traverse along the base and intersections from stations on the base to determine critical points over the area out in front. The method of resection is not usually applicable because this requires that the sketcher go to the point located. *The Base* might, however, be located *some distance in rear of the outpost line,* (if the sketch were being made under fire of the enemy, to avoid exposure in traversing along the line of observation); and from this retired base critical points could be located on the line of observation by intersection or resection. The sketcher would then approach these located points by creeping up from the rear, orient his board flat on the ground and sight necessary critical points over the foreground. The information to be represent-

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ed on the outpost sketch is the same as is shown on a position sketch and on the same scale.

There will often be portions of the base from which good views to the front are not possible. It is therefore necessary to study the ground most carefully from each base station, in order that critical points may be selected which can be seen from at least one other point located along the base, so as to give good intersection angles. For the critical points only a short distance in front, observations must be taken from points correspondingly near each other along the base. To locate critical points far to the front, the extreme ends of the base would probably be used as stations from which to intersect.

It will often be impossible to see more than a small part of one hill lying beyond another, or the lower part of a small ravine may be seen, of which the upper part lies beyond a hill. If, as is often the case, a good estimate can be made of the nature of the hidden area, judging from the visible parts, then the concealed portions should be drawn in broken lines to indicate the method of location used.

Field Glasses are of great assistance in this work in picking out definite objects to intersect on, and in discovering folds of the ground not visible to the naked eye. If two ridges lie generally parallel to the front and at some distance from the base, it will often be possible to discover the farther one only by the line of different light made by the nearer one against its side slope.

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CHAPTER IV.

THE EXECUTION OF A ROAD SKETCH IN DETAIL.

289. The instruments required by a beginner in road sketching are preferably as follows, but others may be used as noted below:

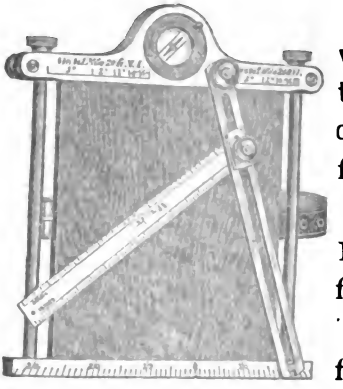

Fig. 149

1. *Drawing Board*, with declinator, on folded tripod, figure 151, p. 290, or Cavalry Sketching Case figure 149.

2. *Loose Ruler*, figure 137, with scales shown, figure 136, p. 242.

3. *Service Clinometer*, figure 138 (see par. 246) carried in upper right breast pocket, secured to it by a strong cord.

4. *An Equipped Pencil, Knife and Ruler Holder*, figure 146, p. 273.

5. *Soft Rubber Eraser.*

6. *Stop Watch and Note Pad*, figure 150 (for mounted work).

METHOD OF WORK, DISMOUNTED.

290. *A Road Sketch* is *normally made mounted* on account of the rapidity of work thereby secured. It is well, however, for the beginner to make

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his first one or two sketches dismounted to become accustomed to the three inch scale and twenty foot contours, before attempting to manage a horse in addition to the work of sketching. There may be occasions too when a horse is not available, so that a sketcher should be able to work with equal facility either mounted or dismounted.

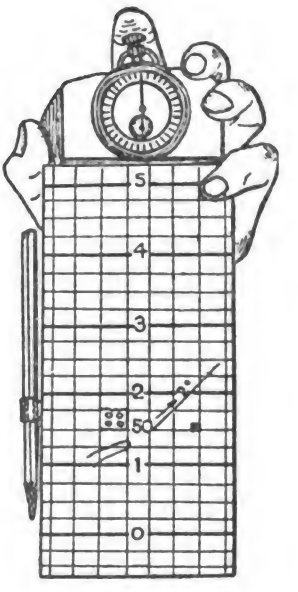

Fig. 150

The method previously given for traversing the base, A B C figure 147, in making a position sketch is, in general, identical with that used in a dismounted road sketch, except that intersection locations are not usually required at more than four hundred or five hundred yards from the road, and no resection work is usually possible. A large part of the work is done by traversing the road and estimating offsets. After the first one or two sketches, the sketcher will not usually leave the road, except to go to the top of some crest a few yards distant to get an extended view. Details will be limited to four hundred yards from the road, except for prominent positions, etc.

There will often be areas within the 400 yard limit, which are not visible from points directly opposite them on the road. These areas, however,

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may usually be seen from some point along the road before or after passing opposite them.

The drawing board may be used in road sketching, with or without the tripod. If the tripod is used in mounted work it should be folded to a single length, figure 151, as it thus furnishes a firm support and also a convenient hand-hold for carrying the board on horse back. More accurate work can be done by using the tripod in this way, without loss of time, than can be done by holding the board in the hands. Some good sketchers use a board with wrist strap, and for important

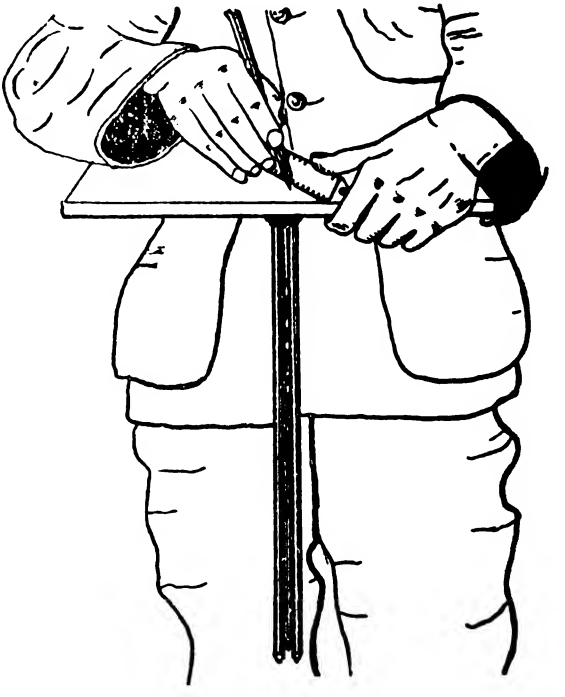

Fig. 151

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sights place it on the ground and lie down prone on the opposite side of the board from the point sighted.

In unimportant sights and in locating details around any station, even when the tripod is attached, the board need not be set up on the ground but may be held pressed against the breast, figure 151. The sight is taken by fixing the eye on the distant object and then glancing quickly down at the ruler and making the necessary adjustment of the ruler's direction. In practicing this method, you should use a board on tripod and check each sight by carefully looking along the ruler. Never sketch with the cord holding the board around your neck.

The method of using the Cavalry Sketching Case is identical in principal with that of the drawing board without a tripod. A sketcher having learned one of these instruments will have no difficulty in using the other.*

TO LOCATE HORIZONTAL DETAILS.

291. 1. *Orient the board,* par. 268, at station A, figure 152,† p. 302, holding it in front of your body, that is between you and the object sighted.

*The advantages of the Drawing Board over other forms of sketching cases:

1. Its larger size gives sufficient area for two miles of position sketch in both directions; and about twelve miles of road sketch by running three traverses across the sheet. It is equally as portable as the Roller Sketching Cases.

2. Being practically square, the full length of the board is available, no matter what the direction of the traverse may be,

†From sketch made by Captain A. W. Bjornstad, 28th Infantry, in the Army School of the Line.

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By glancing every moment or two at the declinator (or compass) see that the needle remains in the meridian. With the declinator, the orientation is effected most rapidly and is free from possible errors of needle reading. The sides of the declinator trough check the vibrations of the needle, and the orientation is correct when the needle

without the necessity of orienting this board in some special position. The Cavalry Case and all similar ones have such a small drawing surface that it is necessary to orient the sketching case so that the traverse extends in the direction of the rollers. This direction of the road to be sketched will often not be known, thus causing the sketch to run off the paper frequently, with resulting delay and annoyance.

3. It has been found of great value in rapid sketching to have **flat sheets**, so that when the parts of the sketch are to be pasted together, the sheets will lie out flat without twisting and curling up, due to being on rollers.

4. **The attached ruler of the cavalry** case is a time consuming device, and should be removed and a loose ruler substituted. Simplicity of each article of equipment is absolutely essential to rapidity of work.

5. **The note book and compass method has no advantage** over the drawing board method and is much slower, because the taking of intelligible notes from compass readings requires as much time as the making of a complete sketch with the board. The notes then require as much time to plot as was used in taking them. The errors mentioned in paragraph 240 are more liable to occur in this method and, in addition, other mistakes and omissions occur because the ground is not visible at the time of plotting. The reason often given for this method is that it can be used in the rain. The taking of notes in the rain is almost as difficult as sketching, and by use of celluloid with a ground surface, a pencil sketch can be made in the rain. This celluloid takes pencil lines readily even when it is perfectly wet. These lines may be readily erased with a soft rubber, but are not erased or smudged due to rubbing of hand and ruler in sketching. This celluloid is more transparent than tracing paper and allows blue prints to be made from the pencil sketches without retracing.

6. The Drawing Board equipment is easily improvised using a box top for the board and any straight stick for the ruler. The compass and tripod are not absolutely essential.

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strikes both sides of the trough with equal force. This can be easily determined by observation, and by listening to the click of the needle against the sides. To orient rapidly, note which side of the trough the north end of the needle (marked N) rests against, rotate the board continuously in this direction until the needle leaves this side and *swings equally on both sides of the meridian.* If the needle is very sensitive it will not come to rest quickly but you need not wait for this if you observe the above rule as to equality of swing. Remember to *see that the orientation is correct during all important sights,* especially along the main traverse. The needle of the Cavalry Case being very short and often sluggish, may appear to be more easily kept on the meridian than a longer needle. This does not mean that the orientation thus secured is better, but quite the contrary.

292. 2. *Take a forward sight along the traverse* toward B. Next sight the prominent critical points within three hundred or four hundred yards of A, figure 152, for example the directions of road to the north, and southwest up the stream south of A B.

In making this sketch, you observe that the road A B is generally straight until the high hill at E is reached; you can therefore afford to spend a little extra time on this forward sight along the traverse, because of the amount of sketching depending on it and the consequent necessity for accuracy. Traverse to station B, noting the strides re-

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corded on the tally register opposite the wire fence and railroad track. You should be able by this time to record your strides so automatically, see par. 229, that *your entire attention can be given to the study of the details to be put in.* You observe that the stream north of the road A B runs parallel to it at about two hundred and fifty yards distance. At first you would verify this estimate by halting at the railroad crossing and taking an intersection sight on the bridge north of A. You also observe in passing that the wire fence, noted before, runs parallel to the road north from A. At the railroad you observe that the track is perpendicular to the road on the south, and curves off to the northwest into a cut ten feet deep and one hundred and fifty yards long.

293. *Methods at B.* Having reached B, orient the board, plot in the roads branching from A and all details between A and B, first scaling off the distance to the wire fence, railroad track and B. The best method of doing this sketching in of details is to sit on the ground facing toward A, and draw in all details free hand, except roads and fences. The board need not be exactly oriented for sketching in details. With a little practice parallel lines for road boundaries can be easily drawn with the ruler. First draw the further line, then slip the ruler toward you and draw the nearer one. This allows you to keep the one first drawn in view and enables you to get the two parallel.

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294. The conventional signs for roads, trees, houses, etc., should be drawn about the size of those in the figure. Telephone and telegraph lines are sufficiently indicated by conventional signs *at wide intervals* as shown. Information concerning bridges, may be shown as indicated in the sketch for the railroad bridge, figure 152, p. 302, (W. T. $\frac{100\times10}{15}$), meaning wood truss, 100 feet long, 10 feet wide, 15 feet high; or it may be tabulated on an edge of a sheet as for bridge (1) and (2), figure 147, p. 284.

295. Having located the details from B to A, sight the stream junction southeast of B, to complete its location. Continue the traverse in the same manner to E, halting from time to time to *plot the details in rear of the point reached.* At E orient the board carefully, sight along the new direction of the road to the crossing F, and toward the prominent hill top X. (If you are using the short tripod your orientations should be by back sight; if you are holding the board in your hands, the orientation will be by compass). Take a sight to G to serve as a check on the traverse to that point by way of F. Where a stretch of road has a number of small bends, but is generally straight, these *accurate check sights far to the front are valuable* in keeping the correct direction, the small bends being drawn in by estimated offsets at the number of strides noted in passing them. To take

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a large number of short sights of one hundred and two hundred yards tends to accumulate errors. *In a long traverse in one generally straight line* as from A to E, *strides should be recorded continuously* for the entire distance, to avoid confusing the point from which the plotting is done and the accumulation of plotting errors.

Now traverse to the crossing F, without halting at Kennedy, but noting the number of strides to the road bend, to the house, and to both ends of orchard. Houses at cross roads (or other prominent points) should be located in their correct position, and the names of owners should be shown, for use as landmarks in the designation of routes of march, etc.

Having arrived at F, you would continue the sketch in the same manner as already explained.

CONTOURING THE ROAD SKETCH.

296. Having located the horizontal details of the sketch, you should go back over the road putting in contours. (It is assumed here, for purposes of description, that you start in again at A to put in contours.) Looking north from A you observe that the ground rises only two or three feet above your present position and falls below your level (800) at the stream. You verify this by noting that the zero reading of the clinometer strikes the ground just beyond the bridge. Orient the board and draw the 800 contour up both sides of the stream to the point estimated as at your present elevation. Also draw in the 800 contour

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on both sides of the stream in the immediate vicinity of A.

Move to B, and read the vertical angle to A ($-1\frac{1}{2}°$), being careful to sight a point as high above the ground at A as your eye is above B. Apply your $1\frac{1}{2}°$ M. D. and find it contained two and a half times between B and A, or B is at elevation 850. The 820 and 840 contours must be put in between the two stations. You observe that the ground near A is flat with a rise of about three degrees near the railroad track, so space the contour to show this. In all your road sketching be sure that the contours (especially on every steep slope) *show accurately the slope of the steepest part of the road* to convey to the commander correct information of the heaviest slopes over which the trains must pass. The spacing of contours on the flatter portions is less important, but must show the character of the slope—concave, uniform or convex.

Now read the slope to the stream junction to the southeast ($-3\frac{1}{2}°$). Remembering that you are at 850 elevation, and noting that the slope is uniform, you place the 840 contour about $\frac{1}{2}$ a full M. D. from B.

You now observe that the Flint House is only about 10 feet above you, and consequently that there can only be the 860 contour around this hilltop as shown. To verify this you read the angle to the highest point of the hill and find a $+2°$ slope just west of the house. Application of M. D. scale shows the hilltop is 15 feet above B or 865.

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You now draw in the contours on both sides of the road between B and A as shown, spacing them to show correctly the ground forms and slopes. The contours should be numbered as soon as finished.

297. The difficulties which you encounter at this station B are exactly those encountered at all subsequent stations throughout the work, but what seem to be insurmountable obstacles to you at first, will gradually become perfectly simple. And this skill will be acquired quickly or slowly, *depending on how carefully you analyze the essential elements of ground forms around each station* in the early stages of the work. The beginner arriving at B looks around him hopelessly trying to pick out the important points to be considered; but as he grows accustomed to the work he will grasp at a glance the critical points to be located and the details to be shown. *Constant study in converting ground distance to map equivalent, and in plotting the location of the contours around the station* is most valuable practice. You now look ahead and observe the slope of the ground on both sides of the road, and note that the road falls gently about 12 feet at the first draw, then rises nearly to the height of B opposite Mottin. You also observe that there is a ridge line (shown dotted in the figure) extending along the north side of the road from Flint to Mottin, where it crosses through the grove, and that consequently the 840 contour must be about equal distance on each side of this ridge line, since the slopes of the hill near its top seem uniform.

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298. *Carrying Elevations Forward.*—From B you can see the road some distance forward; therefore lie down with your eye near the level of the road and take a zero clinometer reading forward. This line of sight strikes the ground about 15 feet below the top and some distance east of the ridge at Hund, and the trees at Mottin about 4 feet above the road. Note this point near Hund for later reference as at 850 elevation. Note carefully the shape of the ground forward, especially the relative heights of the points where ravines cross the road. The horizontal locations of these points have already been determined in your previous work over this course to locate horizontal details. The question often comes up as to the necessity of taking the vertical angles to each small depression such as H and K, where you can readily see that no contour, or at most but one, is to be put in. Such observations are impracticable and unnecessary and would give less accurate results than a direct estimate of the height of these points on account of the short distance involved.

299. Now move to the high point north of Mottin, and looking back observe that B seems a little higher than your position, so you read the angle and find it about $(+\frac{1}{4}°)$. Being curious to see how this agrees with your estimate from B, (see above) you apply the scale of M. D.'s. and find the difference about 6 feet. In order that direct estimates of differences of elevation may agree with those found by clinometer reading and scale of M.

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D.'s., you must have determined your stride scale correctly; and your clinometer must be in adjustment, or its error known.

Now draw in the contours on both sides of the road back to B, making a careful estimate of their position, and noting that the ridge is flat topped and convex shaped.

You already have a reference point of elevation located; so proceed to the top of Hund ridge, studying the ground and noting the number of strides opposite the selected reference point. Estimate the difference of elevation between your position and the reference point (15 feet) and verify it by a slope reading and application of M. D. Continue the work of contouring in this manner throughout the sketch, slowly and with many measurements at first; but gradually depending more on estimates of slopes, elevations and contour positions, as you acquire skill in analyzing ground forms. For instance, from B you should have made an estimate of its height above A to see how it checked with your other determination; similarly the height of Hund ridge should have been estimated from B.

ROAD SKETCH MOUNTED.

300. After you have made about two dismounted sketches, it is well to begin mounted work. The general methods involved are identical with those used in the dismounted work. The greatest difference arises due to the *necessity for controlling the horse,* in the *greater training of the eye re-*

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quired to fix in mind the ground forms while moving rapidly from one station to another, and the *necessity for a more systematic method of work* to secure rapidity. When mounted you have a considerably better position for observation of the ground on account of your height above the surrounding country. You should *do all plotting dismounted* because of the greater rapidity and accuracy of working in this position. The time required to ride between stations at a trot and to dismount and mount at each is small compared with that required for the actual work of sketching. *Every step of the work should be done according to a fixed system.* For instance you should work out one definite method of carrying your board; one certain position to take for sketching immediately on dismounting at each station; a method of keeping time notes, and of keeping the horse at a uniform gait, a definite order of plotting distances, details, and contours.

301. *Use of an Assistant.* If you have an assistant, decide whether he is to keep the uniform rate; to learn the names of owner's of houses; to read slopes; to call your attention to details such as orchards, windmills, telegraph lines, cross roads, etc. Each man must work out the system best suited to his own needs, but the following suggestions are offered (assuming that you have no assistant) for carrying pencils, clinometer, etc.:

302. *To Move Between Stations.* On starting from a station *stop the needle,* swing the board

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over your back, figure 153, and grasp the reins in the right hand. Best control of the horse can be secured by tying a knot in the reins in front of the pommel, and grasping this knot. The folded tripod does not interfere with your freedom of action in taking notes. The left elbow is supported by the board and in turn presses the Board firmly

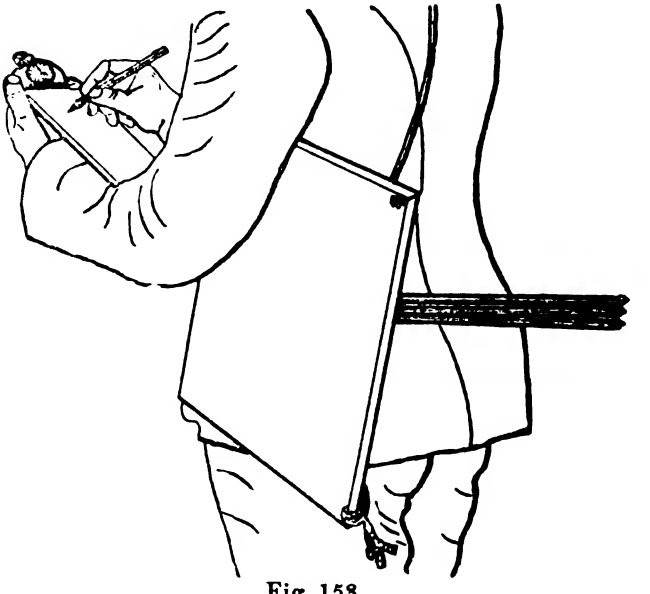

Fig. 153

against your side. If you have an assistant he should carry the Board, grasping the tripod at its top.

Immediately on mounting take the stop-watch-and-note pad (from the lower left blouse pocket) in the left hand, figure 150.*

*The stop-watch-note pad may be purchased through Secretary, The Army Service Schools at 35 cts. each. It consists of a piece of heavy cigar box board 2¾x9 inches, to which is glued

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At the moment the horse starts, press the stop with first finger to start the watch, being careful to see it is set at the proper reading.

303. *Taking Notes on Horseback.*—As important details are passed along the road, note the time and opposite the proper line of the pad jot down a rough symbol on the center line or at the estimated distance from it, according as the location of the detail is on or off the road. These notes will be a great aid to the memory; but as little time as possible must be spent in putting them down, the greater part of the time being used to impress features of the ground on your mind. Some men find it very difficult to make even the simplest notes on a trotting horse; but you can learn to keep sufficiently clear notes on even the roughest horse, by standing up in your stirrups, leaning the body well forward and holding the arms close against the sides while writing. You can also record notes while posting. During the entire time spent in passing from one station to another, except for

the note pad shown. Each fifth horizontal line is marked to show minutes of travel. The three light lines between each two heavy ones represent 15 seconds (quarter minutes) each. The spaces between the vertical lines represent 100 yards each. The stop watch is secured to the back by two wooden pieces screwed on. The best type of stop watch is one which can be stopped and then will continue forward from this point when the stop is pressed again, so that continuous record may be kept over long straight courses. The watch should have a device for quickly setting the hand back to zero. A foot ball timer (price $1.50 Secretary Service Schools) is fairly satisfactory but not as reliable as a good stop watch. It is well to make a pencil holder on the side of the pad, as shown in figure, for a soft blunt pencil, so that the drawing pencil need not be used in taking notes.

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the brief intervals required to record notes, you should devote every faculty to a careful study of the ground, the trace of contours, and other essential details.

304. *Distance Between Halts.* In the first two or three sketches you should not travel more than about one minute between stations. Later this distance may be increased as your skill progresses until you can travel for 3 or 4 minutes without halting. Suppose you pass a little draw on the road (at 1 minute and 15 seconds) falling to the left; a house distant 190 yards to the right at 1:30; an orchard on the left extending from 1:30 to 1:45; a ridge line at 1:30 found to be 850 elevation from your last station, extending 45 degrees to right front, with a —2 degree slope. These facts can be recorded in a moment as shown on the pad. Or some simple system of letters may be used, such as R for ridge, V for valley, on lines in the proper direction; an arrowhead for down slopes, etc.

305. *Procedure at a Station.* On arriving at a station, immediately upon halting press the stop to get the correct time. Dismount, throw the Board cord from over your head, release the needle, spread out the tripod legs, at the same time rotating the board horizontally to orient it. Back sight orientation is more accurate and will often be possible even when no tripod is used, by laying the board on the ground, and turning it until the last station is sighted. Waste no time in orienting.

The horse should be trained to stand without be-

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ing held; but if necessary throw the rein over a post or place your foot on it (if you have no assistant). With tripod, you will find it easier to take your observations for direction kneeling on the opposite side of the Board from the point sighted. For sketching in details, however, a sitting position on the road side is best and most comfortable. After your traverse and other important directions are located do not worry about keeping an exact orientation during the work of sketching details. As soon as your Board is oriented plot your present station; pick out and sight your next forward point, also take any intersection or forward check sights, so that exact orientation will then not be so necessary for the remaining work. Determine the elevation of your present station with reference to the last known point by the methods heretofore given, that is with clinometer and M. D. scale, or barometer, or estimation, etc., according to the practice you have had. Locate any other necessary elevations and plot all details and contours up to your position. After several sketches have been made, you can begin to plot details forward from each station for about 15 seconds of travel, by estimation. This will relieve you of the necessity of taking notes until about 30 seconds have been passed. Move to next station using the same methods.

306. In rapid sketching, time may be saved on roads with frequent bends by *halting only at each alternate* bend. For example from E draw a ray

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to F, noting the time of passing F but not halting there. At *G* plot *f* on the ray drawn from E; orient by needle, and pivoting the ruler on *f* draw a ray toward *G*, plotting on this ray the position of *g* from the time scale.

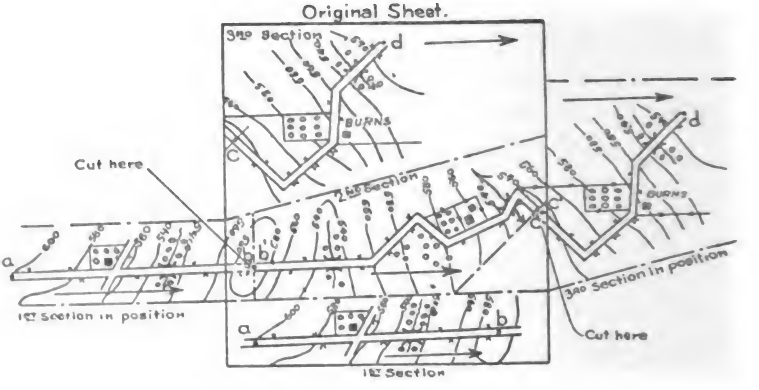

Fig. 154

307. *In case the sketch runs off the sheet* beyond *b*, figure 154, draw in the details a few yards *in front* of station B. Then assume a new point (*b'*) near the edge of the sheet, also to represent B, so chosen that the sketch forward from here will fall across the longest dimension of the unused part of the sheet. On the sheet near *b'* sketch in the details a few yards *in rear* of B, before moving forward. If no space is available on this sheet replace it by one of the extra sheets carried under it on the Board. When the sketch is completed, cut apart its different sections (on the broken and dotted lines) and place them together with all meridian edges parallel and *the two corresponding points on the sheets for any ground point, lying one directly*

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over the other. Lay the ruler perpendicular to the traverse through the station point (as *b*) and cut both sheets through on this line. Remove the two ends cut off and join the parts together *without overlap* by means of adhesive tape or on another piece of heavy paper. Join up the details across the cut edges. Where the sketch is made on tracing paper and reproduction is required, the adhesive tape should be used. B, C, etc., should be on a straight portion of the road and *not at a bend,* to aid in orienting the sections.

308. The *rate of sketching* possible by these methods should be about 2 to 2½ miles per hour for men of average ability, after a month's practice. Men with greater aptitude can make from 3 to 4 miles per hour; and the best sketchers can make as much as 5 miles per hour. These rates refer to the *completely finished* sketch, ready for use. In ordinary service 2½ to 3 miles an hour would be sufficient, but the more rapid methods are very valuable for making a reconnaissance in a limited time, and of especial value to staff officers in reconnoitering routes and positions.

EXECUTION OF PLACE SKETCHES.

309. A Place sketch is made under the supposition that the sketcher is limited to a single point of observation overlooking the area to be sketched. The details to be shown are the same as on a position or outpost sketch. If made to extend a road or position sketch farther toward the enemy than can be reached by the sketcher the place sketch will

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be on the scale of the sketch thus extended, otherwise at 6 inches=1 mile, 10 foot contours.

The sketcher must have acquired considerable skill in sketching and in making estimates of distances, slopes and elevations before he can successfully make a place sketch. The methods of work heretofore described for position sketching are followed except that all control points are located by determining distance with range finder (or by estimation), elevations with clinometer (or by estimation), horizontal angles of direction, with plane table or compass. For use of range finder see par. 214, *Military Topography*. First locate stream lines, next roads, then hill tops, and finally contours and minor details.

The place sketch is made under the same conditions as a perspective sketch, but has the advantage that it represents truly to scale the features of the ground in their relation to each other as estimated by the sketcher, and to be interpreted need not be examined from the point occupied by the sketcher. The sketcher's estimates may be in error, but his sketch will show the ground according to these estimates. A perspective drawing, on the contrary, furnishes no means of determining relations of distance, slope and elevation. They are valuable, however, for persons ignorant of map reading, or to illustrate descriptions of military positions for non-military readers. All staff officers and especially artillery reconnaissance officers, should be skillful place sketchers, since this ability will save the time ordinarily used in explanation of important features of the terrain to battery or

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battalion commanders and enable the batteries to open fire more quickly and accurately than otherwise.

POINTS TO BE OBSERVED IN SKETCHING.

1. Be sure your intersection and resection points are well marked to avoid sighting back on the wrong point.

2. Study your area carefully and do not sight any point that is not going to help your work. There is a tendency with all beginners to try to show too minute details and to take too many controlling points. A few minutes used in studying the area before commencing work will usually be well spent.

3. Keep constantly in view the scale of your sketch, the contour interval, and remember the smallest distance that can be shown.

4. Be sure your orientations are correct and that the Board is clamped after orientation. The forward sight to the next station should be made as soon after orientation as your position is plotted.

5. After the first set up always orient by a back sight if possible, especially if in the vicinity of iron, or strong electric currents. However, if you can't locate a point in rear to orient on, use the needle without hesitation.

6. Do not leave a station until all the details up to that point are put in. You may not have time to return that way. Finish your sketch as you go, the lines may be retraced and the sketch cleaned up indoors if the emergency demands it, but all

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data should be put on in the field. *You should make it a fixed rule to have a finished sketch up to the point occupied, before moving on to another.*

7. *Try to put equal care and time on all parts of the sketch.* Avoid excessive care at first followed by excessive haste near the end. A good sketcher should be able to do from one to two square miles of accurate sketch per day depending on the difficulty of the ground.

Note: For Exercises in sketching see par. 347.

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CHAPTER V.

TOPOGRAPHICAL RECONNAISSANCE REPORTS.

310. *Reconnaissance* is the military term used to designate the work of troops or individuals when gathering information in the field. The general subject of Reconnaissance is divided into two parts: (1) that which relates especially to the strength, position and intentions of the enemy, and (2) that which relates especially to the terrain in its relation to the military situation.

Reconnaissance of the enemy is within the province of tactics and is treated under the head of the Service of Information in the Field Service Regulations.

311. By *Topographical Reconnaissance* is meant the obtaining and recording of all the needful information of a portion of the terrain in the shortest possible time and within the limits of accuracy required for the operations of troops in the field.

A Topographical Reconnaissance in general consists of:

1. *A Sketch.*
2. *A Report.*

The method used to secure and record the desired information of the terrain are therefore treat-

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ed under the two headings, Military Topographical Sketching and Topographical Reports.

As much as possible of the desired information should be shown on the sketch, on account of the greater clearness and brevity thus secured. The report should amplify the sketch in matters which cannot be shown thereon, such as conditions of roads, quantities of supplies, etc. It should in general be written on the face of the sketch sheet in tabulated form; or on a letter size sheet of paper attached thereto.

For the means and methods used in making Military Sketches, see Part III, pars. 223-309.

312. *Military Topographical Reports*: *The Report should relate only to those subjects which are required by the orders for the reconnaissance so that no time may be wasted in gaining irrelevant information. It should be written clearly, and be as brief as possible* consistent with clearness. The *paragraphs* should be *numbered* serially for ready reference. *References* to the sketch should be made by means of numbers enclosed in parenthesis, thus: "*Road* (1)—(2) 18 *feet wide, macadam, good repair.*" It is well to place all numbered references on the sketch before writing out the complete report so that these references on the sketch will extend from beginning to end in order and thus be easily referred to. It is a good plan to make these references on the sketch in red pencil so that they will catch the eye at once. The report should be dated and signed by the officer making the reconnaissance.

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Names of Places should be in BLOCK CAPITALS, and should be spelled phonetically when the spelling and pronunciation are different. *Relative Terms* (such as before, behind, etc.) should be avoided, points of the compass being used except that the terms "right," "left" are to be applied to the banks of a stream assuming the writer to be looking down stream. The term *"open country"* means that it is free from hedges, undergrowth and other obstacles obstructing view and passage; *"close country"* is the reverse of this.

313. A *Road Reconnaissance* should procure data on the following subjects:*

314. *The Road*: *Gradients, especially the steepest;* width of roadway; if paved, width, kind and condition of paving; width and depth of side ditches, and whether wet or dry; if not paved, character of soil, sand, clay or gravel; *kind of fences* and width between them. The sketch should also show whether the road is an *embankment* or *cutting*; where wagons cannot double or pass, and where foot troops cannot march along the side between the wagon track and *fences; commanding heights within infantry or artillery range.*

315. *Bridges*: Material of piers and abutments *type* and *material of superstructure,* as *girder, truss, arch, suspension, wood, steel, stone* etc.; *width of roadway,* and clear headroom; safe load.

*From the Engineer Field Manual. Items of a reconnaissance, shown in *italics* should usually be shown by the sketch; those in ordinary type by the report. Features not fully shown in the sketch are amplified by the report.

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Of bridges over the road, clear width and height; over streams, the nearest bridge above and below and whatever information can be obtained about them.

316. *THE COUNTRY.—Character of cultivation or natural vegetation; areas and density of timber, underbrush, vines,* especially poisonous ones; *marshes and fords, kinds of fences,* nature of soil, *general configuration of surface, especially high hills, long ridges or valleys, bluffs or slopes too steep to scale, and practicable routes to their crests.*

317. *STREAMS CROSSED.—Name, location, width,* depth and surface velocity in swiftest current; velocity noted as sluggish, moderate, quick or swift; elevation of high water marks in relation to the road; *which bank is the higher at crossing and above and below, and how much;* accessibility of water for stock; *fords at or near crossing;* length, depth and *steepness of approaches; levees or embankments, height and thickness on top;* if navigable, to what distance above and below and for what class of vessels—steamers, flatboats, rowboats.

318. *TOWNS AND VILLAGES* passed through—*Name, location on map,* and population. *Names of streets to be traversed.* Material, as stone, brick, frame, log; size, 1, 2, 3 stories; and distribution, close or scattered, of the houses in those streets; *gradients of intersecting streets; location of depots, post telegraph and telephone offices; of*

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drinking fountains and watering troughs; of elevators, storehouses, or other accumulations of food and forage; of blacksmith, wagon and machine shops.

When ordered to make a complete examination of a town or village, note besides the foregoing, *location* and size of *principle buildings, halls, court and school houses, churches, banks, jails,* and their ownership; sources, maximum quantity and distribution of water supply; sanitary conditions and disposal of wastes; *location of railroads, depots, freight houses, sidings, etc.,* for all roads entering from the surrounding country the same information as scheduled above for streets; *location* and extent of *open spaces,* and of *large substantial buildings standing apart; location and extent of high ground within range, especially that from which streets can be enfiladed.*

319. *RAILROADS CROSSED.—Name, location,* gauge, *single* or *double track, sidings, and loading platforms at point of crossing; crossing at grade, over or under; distance, and name of nearest station each way; direction of nearest roundhouse, shops, etc.* General condition of stations as to defensibility—*command of surrounding ground,* and material of construction in the buildings.

RIVER RECONNAISSANCE.

320. If, when standing on the bank facing across the stream, the current flows from left to right, the observer is on the right bank; if from right to left, he is on the left bank.

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321. *THE VALLEY—General configuration, heights of limiting ranges,* and *positions of passes and roads crossing them; commanding ground from which a stretch of the channel of considerable length can be enfiladed by artillery; forest growth on or near banks;* soil and cultivation of the valley; *roads parallel to river and means of access* to them from the river.

322. *THE STREAM*—Its *width,* depth and velocity, navigability, as for steam boats, row boats, and head of navigation for each; nature of obstructions to navigation and possibility of removing or avoiding them; season of high and low water, average rise and fall; rapidity of rise and fall and causes; amount of drift; character of *banks* and *relative command.* Quality of water, amount and kind of sediment borne; usual period and thickness of ice. (Ice 2 inches thick will support single men; 3½ inches will bear infantry in column; 10 inches will bear any military load.)

323. *Tributaries and Canals.—Width,* depth and navigability, *means of crossing.* Nature and purpose of canals; *dimensions* and lifts of locks; time for lockage; means of destroying locks and effect of destruction; floating plant found.

324. *Bridges and Fords.—As in road report.* Also for bridges note position of the channel and navigable width between piers; height of arches and lower chords above the water at different stages; dimensions and operation of draw spans. Note the *exact position of fords* and marks on both banks

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by which they may be found; length, width and nature of bottom; velocity of current; position of deep holes; aids to crossing. Fords should not be more than 4 ft. 4 ins. for cavalry, 3½ ft. for infantry and 2 ft. 4 ins. for guns and ammunition. Note nature of approaches to bridges and fords; width of roadway, slopes, soil, effect of water and traffic. Note especially the defensibility of bridges and fords.

325. *Ferries, Boats and other means of crossing.—Position of ferries and approaches,* practicability for horses and loaded wagons; size, number and kind of boats; method of propulsion; sites for military bridges or ferries; character of site for construction, use and defense; *proximity of islands and other tributary streams;* approaches and slope of banks; width of river and maximum surface velocity of current; materials for the construction or repair of boats, bridges or ferries.

326. *Inundations.—Places suitable for inundations by damming or obstructing a narrow bridge span,* or *by cutting a levee or dyke.* Note raised roads on ground liable to natural or artificial inundations and the safest routes to follow by known land marks when the road is overflowed. (An extensive inundation 2 ft. deep on level ground is a serious obstacle unless the roads are very sound and marked by trees, posts, etc. Even when so marked a dip in the roadbed of 3 or more feet may render the road impassable. A railroad bed is soon washed out even by a slight overflow.)

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RECONNAISSANCE OF A RAILROAD.

327. *The line. Local name, terminal points and distances between stations and other points;* gauge; *single or double track;* condition of roadbed, ties and rails; drainage and liability to overflows or washouts; facilities for repair; condition of right of way for marching troops along the line.

328. *Tunnels and Bridges.—Number and location; dimensions;* strength of bridges; means of destroying and repairing; of blocking traffic.

329. *Rolling Stock.*—Number and nature of engines and cars available; capacity for transporting troops between given points; facilities for constructing armoured trains, as spare rails, old boilers, etc.; *location* and capacity of the shops and store yards.

330. *Stations:—Name and location*; facilities for entraining and detraining troops with wagons and horses; platforms on through line and *sidings, ramps; side tracks, number* and capacity; *turn tables; water tanks;* fuel supply; storage facilities; derricks or cranes; *cross-over for teams* and pedestrians. Facilities at hand for hospitals, camps, depots; for feeding men, heating coffee, watering horses during temporary halts.

RECONNAISSANCE OF A WOOD OR FOREST.

331. Note *all roads and paths,* and *all hills, ravines, and streams within the wood or skirting the edges;* kinds of trees, *density of growth;* underbrush, prevalence of poisonous shrubs and vines; *marshy or large open spaces;* practicability of

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forming new roads by cutting: creation of obstacles by felling trees; if there are no roads, *traverse the shortest practicable path between the point of entrance and the point of exit,* and mark boulders or blaze trees, set stakes or otherwise indicate this path, and also give compass bearings of the route to be followed. Note the *exterior from the woods, whether parts of the edge flank other parts; connection with neighboring pieces of wood by scattered trees or clearings; undulations of the ground that would give cover to attacking force or to defenders.*

RECONNAISSANCE OF MOUNTAINS.

332. Note the *number and positions of passes through the mountains, of roads and trails leading to these passes,* their condition, practicability, and means of repair; *steepness of slopes on the sides of roads;* means of constructing additional roads; *water courses, their direction,* nature, and time of floods, *means of crossing.* Note *ravines* and *open glades on mountain sides, lookout points,* and *good signal stations;* note time and duration of snow drifts on roads or passes; depth of drifts and possibility of removing them or traveling on the surface of the snow. Note *extent* and nature of *forest growth.*

RECONNAISSANCE FOR A CAMP OR WINTER QUARTERS.

333. *Site, location, elevation, and area;* sanitary features, such as drainage, dryness, and general character of top soil; *proximity of swampy*

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ground or stagnant ponds. For camp of a regiment of infantry allow approximately 160x180 yards; for a regiment of cavalry 200x300 yards; for a regiment of light artillery 240x300 yards. (For requirements of camp sites see F. S. R., Art. VI.)

334. *Communications.*—Sufficiency of existing *roads and paths, maximum grades,* probable condition under heavy traffic and in bad weather, location and kind of materials available for improvement or repair; *railroad or water communications* and *terminal facilities of same.*

335. *Water and Fuel.—Location,* kind and quantity of fuel at hand; quality and quantity of water, facilities for filling water carts, for watering animals and for washing and bathing; nature of supply, as wells, springs, running streams, and its reliability.

336. *Shelter and Conveniences:—Proximity* of trees, brush, wood, hay, and straw for huts and bedding; *of markets; of towns and villages.*

RECONNAISSANCE OF A POSITION.

337. This problem usually includes the selection of the position and is therefore tactical as well as topographical. Certain relations and conditions must be observed in the selection and the extent and degree in which they are found must be shown on the map or in the report. *The position and ground in front* to artillery range, to be shown by a contoured sketch at 6 inches to 1 mile.

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338. *The length of the position* should be proportional to the force available for its occupation. Exact rules cannot be given.

339. *The flanks must be secure.* Impassable natural features, a *river, a mountain* or *stream* form the best flank. Lacking these, a *wood,* a *cliff* or a *high hill* will serve. Even with these features absent the flank may be strengthened by the construction of a strong earthwork, but the general rule obtains that natural weakness of the flanks must be made up by a greater number of men or by the substitution of cavalry for infantry in case the ground favors the movements of mounted troops. If the flanks are naturally strong the line should be withdrawn to make the entire position reentrant; if the flanks are naturally weak, the connecting line should be held so as to make the position straight or salient.

340. *The depth of the position,* or its extent in rear of the firing line, should afford natural cover for supports, reserves and trains, which may require a total depth of 800 to 2,400 yards; but a short position may be relatively shallower than a long one. Three or four *parallel ridges,* 300 to 600 yards apart, with the intervening ground practicable, forms an excellent position. If the first ridge is somewhat higher than the rest, so much the better. *What cover there may be for the component parts of the force, whether natural or artificial, fences, ditches, trees, etc., should be shown* or described. If digging is necessary, its amount and the character of the soil should be stated. *Strong points in*

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front of the line, which may be occupied as outposts should be shown.

342. *Communication* should be free in every direction, concealed so far as possible from the enemy's view. *All communications* perpendicular and parallel to the front to be shown on the sketch.

343. *Artillery positions* are required when that arm is represented in the occupying force, as will usually be the case. They should permit the guns to sweep all ground in front of the position over which the enemy can advance, to the limit of effective range. Every point in front of the position and within range which commands any part of it is an element of weakness.

344. *Ranges* at which the enemy can be seen and reached by artillery fire, the *points beyond rifle range covered* by such fire and its *relative command of adverse artillery positions should be shown* or described. If possible *similar information* should be obtained of the *ground likely to be occupied by the enemy* in forming for attack or in taking up a counter position.

345. *A position occupied by the enemy* must be reconnoitered from a distance and few details can actually be seen. Valuable inferences may be drawn by remembering that the enemy has probably chosen his position according to the principles above given.

346. *Flanks.*—Especial attention should be given to the flanks and to the feasibility of turning one of them.

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CHAPTER VI.

EXERCISES IN SKETCHING.

347. Sketching consists of measurements and estimates of relations on ground and maps, and more or less mechanical operations with pencils and scales. There will be a large number of distinct operations in any single sketch. And though each individual operation is in itself simple, yet the beginner who attempts at first to draw a complete sketch is invariably lost in a mass of details, imperfectly understood after a more or less careful reading of the text. Consequently, it is important that each detail be mastered singly; not by a study of the text alone, but by study supplemented by practice on the ground. To assist beginners in sketching who have no instructor, and as a guide for a systematic method to be followed in the instruction of classes, the following exercises on the ground are suggested. These exercises should be conducted in the vicinity of the Post on ground which has been previously sketched by a good sketcher or of which an accurate map exists:

348. Area I. For position, outpost and place sketches, an area about ½ to 1 square mile is sufficient. Scale 6″=1 mile, V. I.=10 feet.

Area II. For road sketching exercises a road sketch or map about two miles long is necessary.

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Scale 3″=1 mile, V. I.=20 feet. Each beginner should be furnished blue prints of these areas.

EXERCISES.

349. The work should be taken up in the following order: frequent indoor practice in tracing the contours on a well drawn map, in order to acquire facility in representing the forms later to be observed on the ground; next, frequent practice in contouring sheets on which are shown only stream lines and heights of hill tops, to acquire facility in contouring, see plate 5, page 24; then position sketch, outpost sketch, road sketch, place sketch. The paragraphs of the text referred to should be diligently studied before the particular exercise is undertaken, and should be read as necessary during the exercises.

POSITION SKETCHING.

Exercise 1.

(a) Determine your stride (pars. 228, 229).

(b) Make a working scale of strides (par. 229).

Note: Those who have difficulty in making scales may secure them of any desired length of stride or rate of speed from the Secretary Service Schools.

(c) Test the correctness of the scale (par. 230) and make any necessary changes in it.

Exercise 2.

Choose in Area I some road or path having frequent changes of direction and varying slopes. Traverse this road (par. 268, 278) plotting only the double lines (for width apart of bounding lines

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of roads see figures 148, p. 284 and 152, p. 302) or a single dotted line for the path. Halt (a) at every change of direction, (b) at every change of slope, (c) often to estimate the distance to points in advance on the route. The halt (a) is first for the purpose of noting and plotting the new direction on the sketch (par. 237); the halt (b) is made to estimate the slope, par. 251, and difference of elevation (par. 258) from top and bottom of the slope. Having made all of these estimates as carefully as possible, check each of them by comparison with the blue print, using the scale of M. D's. to verify the slope, the marked elevations or contours to check elevations; the counted strides to check the distances.

Now having fixed to your satisfaction the slope between the two points, space in the contours along that slope on your sketch by eye, checking the estimate with scale of M. D's. (par. 272). Next note the number of contours along this slope from the difference of elevation between its top and bottom (par. 273). Space these by eye to show the particular kind of slope (par. 272). Check the results from the blue print.

Repeat the above exercises until (1) your length of stride is accurately found (2) you thoroughly understand the methods of orientation and plotting of the traverse and the making and verifying of estimates.

Note: Exercise 2 is to develop a fixed habit of verifying all estimates. Rapidity comes later.

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Exercise 3.

Traverse the same road as in exercise 2, performing the same operations and in addition, locate by intersection (par. 269), (a) the top of each hill, (b) the juncture of each two streams and water flow lines, and their heads on both sides of the traverse for ½ mile. Use field glasses to pick out definite points to sight on and see if you are at any time unable to get a second observation on any point sighted. If so find out why, and try it again. Much time is wasted by taking one observation on points and then not finishing their location.

Next move back over the traverse and (a) estimate the slope to each point located, (b) check the estimate by reading the slope with clinometer (par. 251). Then estimate the difference of elevation from your stations to these intersection points. Space the contours by eye, checking etc., as in exercise 2 for work on the traverse.

Exercise 4.

Having traversed the road in exercise 2, set up your board (par. 268) at a station on it, and plot the direction of three or four hill tops off the road. Move to one of these hills and set up in the direction line observed and locate yourself by resection (par. 270). See how this location agrees with that by intersection on this point. Repeat on each of the other hill tops sighted, until you are entirely familiar with this method of resection.

Next locate points by resection using the needle for orientation (par. 270, 2nd method) and compare the results obtained with those by the first method of resection.

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Exercise 5.

(a) Pick out a base line in Area I and see how well it fulfills the conditions of par. 277.

(b) Traverse this base (par. 278), locate critical points (par. 266) over the area by intersection and resection.

(c) Go back over the area and sketch in by eye the horizontal details (figure 147, p. 284, par. 276) such as streams, water flow lines, roads, railroads, telegraph lines, trails, crest lines of ridges, hill tops, orchards, houses, etc.

Exercise 6.

(a) Begin at your initial station and locate the elevations of all critical points by estimation (par. 257), checked by slope readings and application of scale of M. D's., par. 272.

(b) Having found the elevations of the critical points space in the contours by eye, par. 284, checking with the blue print.

Exercise 7.

(a) Make a complete sketch of the flat details as in exercise 5 on an entirely new area.

(b) Contour the above as in exercise 6, par. 283.

Exercise 8.

Make the complete sketch of the area in exercise 7, showing at the same time all horizontal details and the contours par. 286. In this exercise finish up all work in rear of each station (par. 282) before leaving it.

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Exercise 9.

(a) Select an outpost line and traverse this as a base (par. 278) at the same time locating critical points as far to the front as the ground is visible (par. 288).

(b) Return along the base drawing in all horizontal details and contours as indicated in preceding exercises.

ROAD SKETCHING.

Exercise 10.

(a) Make your scale of strides at 3″ to 1 mile, par. 229.

(b) Rate your sketching horse (par. 231) at a walk and trot.

(c) Construct a scale of walk and of trot (par. 232 and par. 19, prob. 3).

Exercise 11.

(a) Traverse (par. 291 et. seq.) the road area II, dismounted, locating all flat details on the road, and, by intersection, to within 400 yards on each side. Each point should first be estimated as an offset (par. 271) and then checked by careful location.

(b) Go back over the road and contour it by estimating the elevations of critical points, par. 257, and the contour spacing, par. 272.

Note: Remember that contours are spaced the same distance apart for the same slopes on both road and position sketches (par. 226).

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Exercise 12.

Make a complete contoured sketch carrying on the horizontal locations and the contours together, along the road in exercise 11, par. 296.

Exercise 13.

Repeat exercise 11 mounted (a), at a walk (b) at a trot, par. 300.

Exercise 14.

Repeat exercise 12 at a trot, being careful to have a complete sketch up to each occupied station and about 15 seconds in advance before moving forward, par. 305.

Exercises similar to the above may be drawn up for place sketching following the principles in the text.

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TABLE I.

$$(H = (c + f) \cos a + s \cos^2 a.)$$

$$(C = (c + f) \sin a + \tfrac{1}{2} s \sin 2a.)$$

Horizontal Distances and Differences of Elevation from Stadia Readings.

Minutes	0°		1°		2°		3°	
	100 × Cos.² a Hor. Dist.	100 × ½ Sin 2a Diff. Elev.	100 × Cos.² a Hor. Dist.	100 × ½ Sin 2a Diff. Elev.	100 × Cos.² a Hor. Dist.	100 × ½ Sin 2a Diff. Elev.	100 × Cos.² a Diff. Elev.	100 × ½ Sin 2a Hor. Dist.
0	100.00	0.00	99.97	1.74	99.88	3.49	99.73	5.23
2	100.00	0.06	99.97	1.80	99.87	3.55	99.72	5.28
4	100.00	0.12	99.97	1.86	99.87	3.60	99.71	5.34
6	100.00	0.17	99.96	1.92	99.87	3.66	99.71	5.40
8	100.00	0.23	99.96	1.98	99.86	3.72	99.70	5.46
10	100.00	0.29	99.96	2.04	99.86	3.78	99.69	5.52
12	100.00	0.35	99.96	2.09	99.85	3.84	99.69	5.57
14	100.00	0.41	99.95	2.15	99.85	3.90	99.68	5.63
16	100.00	0.47	99.95	2.21	99.84	3.95	99.68	5.69
18	100.00	0.52	99.95	2.27	99.84	4.01	99.67	5.75
20	100.00	0.58	99.95	2.33	99.83	4.07	99.66	5.80
22	100.00	0.64	99.94	2.38	99.83	4.13	99.66	5.86
24	100.00	0.70	99.94	2.44	99.82	4.18	99.65	5.92
26	99.99	0.76	99.94	2.50	99.82	4.24	99.64	5.98
28	99.99	0.81	99.93	2.56	99.81	4.30	99.63	6.04
30	99.99	0.87	99.93	2.62	99.81	4.36	99.63	6.09
32	99.99	0.93	99.93	2.67	99.80	4.42	99.62	6.15
34	99.99	0.99	99.93	2.73	99.80	4.48	99.62	6.21
36	99.99	1.05	99.92	2.79	99.79	4.53	99.61	6.27
38	99.99	1.11	99.92	2.85	99.79	4.59	99.60	6.33
40	99.99	1.16	99.92	2.91	99.78	4.65	99.59	6.38
42	99.99	1.22	99.91	2.97	99.78	4.71	99.59	6.44
44	99.98	1.28	99.91	3.02	99.77	4.76	99.58	6.50
46	99.98	1.34	99.90	3.08	99.77	4.82	99.57	6.56
48	99.98	1.40	99.90	3.14	99.76	4.88	99.56	6.61
50	99.98	1.45	99.90	3.20	99.76	4.94	99.56	6.67
52	99.98	1.51	99.89	3.26	99.75	4.99	99.55	6.73
54	99.98	1.57	99.89	3.31	99.74	5.05	99.54	6.78
56	99.97	1.63	99.89	3.37	99.74	5.11	99.53	6.84
58	99.97	1.69	99.88	3.43	99.73	5.17	99.52	6.90
60	99.97	1.74	99.88	3.49	99.73	5.23	99.51	6.96

Table of Corrections (to be added)

For c + f	(c + f) cos a	(c + f) sin a	(c + f) cos a	(c + f) sin a	(c + f) cos a	(c + f) sin a	(c + f) cos a	(c + f) sin a
= 0.75	0.75	0.01	0.75	0.02	0.75	0.03	0.75	0.05
= 1.00	1.00	0.01	1.00	0.03	1.00	0.04	1.00	0.06
= 1.25	1.25	0.02	1.25	0.03	1.25	0.05	1.25	0.08

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Minutes	4°		5°		6°		7°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	99.51	6.96	99.24	8.68	98.91	10.40	98.51	12.10
2	99.51	7.02	99.23	8.74	98.90	10.45	98.50	12.15
4	99.50	7.07	99.22	8.80	98.88	10.51	98.48	12.21
6	99.49	7.13	99.21	8.85	98.87	10.57	98.47	12.26
8	99.48	7.19	99.20	8.91	98.86	10.62	98.46	12.32
10	99.47	7.25	99.19	8.97	98.85	10.68	98.44	12.38
12	99.46	7.30	99.18	9.03	98.83	10.74	98.43	12.43
14	99.46	7.36	99.17	9.08	98.82	10.79	98.41	12.49
16	99.45	7.42	99.16	9.14	99.81	10.85	98.40	12.55
18	99.44	7.48	99.15	9.20	98.80	10.91	98.39	12.60
20	99.43	7.53	99.14	9.25	98.78	10.96	98.37	12.66
22	99.42	7.59	99.13	9.31	98.77	11.02	98.35	12.72
24	99.41	7.65	99.11	9.37	98.76	11.08	98.34	12.77
26	99.40	7.71	99.10	9.43	98.74	11.13	98.33	12.83
28	99.39	7.76	99.09	9.48	98.73	11.19	98.31	12.88
30	99.38	7.82	99.08	9.54	98.72	11.25	98.29	12.94
32	99.38	7.88	99.07	9.60	98.71	11.30	98.28	13.00
34	99.37	7.94	99.06	9.65	98.69	11.36	98.27	13.05
36	99.36	7.99	99.05	9.71	98.68	11.42	98.25	13.11
38	99.35	8.05	99.04	9.77	98.67	11.47	98.24	13.17
40	99.34	8.11	99.03	9.83	98.65	11.53	98.22	13.22
42	99.33	8.17	99.01	9.88	98.64	11.59	98.20	13.28
44	99.32	8.22	99.00	9.94	98.63	11.64	98.19	13.33
46	99.31	8.28	98.99	10.00	98.61	11.70	98.17	13.39
48	99.30	8.34	98.98	10.05	98.60	11.76	98.16	13.45
50	99.29	8.40	98.97	10.11	98.58	11.81	98.14	13.50
52	99.28	8.45	98.96	10.17	98.57	11.87	98.13	13.56
54	99.27	8.51	98.94	10.22	98.56	11.93	98.11	13.61
56	99.26	8.57	98.93	10.28	98.54	11.98	98.10	13.67
58	99.25	8.63	98.92	10.34	98.53	12.04	98.08	13.73
60	99.24	8.68	98.91	10.40	98.51	12.10	98.06	13.78
For (c + f)								
= 0.75	0.75	0.06	0.75	0.07	0.75	0.08	0.74	0.10
= 1.00	1.00	0.08	0.99	0.09	0.99	0.11	0.99	0.13
= 1.25	1.25	0.10	1.24	0.11	1.24	0.14	1.24	0.16

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Minutes	8°		9°		10°		11°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	98.06	13.78	97.55	15.45	96.98	17.10	96.36	18.73
2	98.05	13.84	97.53	15.51	96.96	17.16	96.34	18.78
4	98.03	13.89	97.52	15.56	96.94	17.21	96.32	18.84
6	98.01	13.95	97.50	15.62	96.92	17.26	96.29	18.89
8	98.00	14.01	97.48	15.67	96.90	17.32	96.27	18.95
10	97.98	14.06	97.46	15.73	96.88	17.37	96.25	19.00
12	97.97	14.12	97.44	15.78	96.86	17.43	96.23	19.05
14	97.95	14.17	97.43	15.84	96.84	17.48	96.21	19.11
16	97.93	14.23	97.41	15.89	96.83	17.54	96.18	19.16
18	97.92	14.28	97.39	15.95	96.80	17.59	96.16	19.21
20	97.90	14.34	97.37	16.00	96.78	17.65	96.14	19.27
22	97.88	14.40	97.35	16.06	96.76	17.70	96.12	19.32
24	97.87	14.45	97.33	16.11	96.74	17.76	96.09	19.38
26	97.85	14.51	97.31	16.17	96.72	17.81	96.07	19.43
28	97.83	14.56	97.29	16.23	96.70	17.86	96.05	19.48
30	97.82	14.62	97.28	16.28	96.68	17.92	96.03	19.54
32	97.80	14.67	97.26	16.33	96.66	17.97	96.00	19.59
34	97.78	14.73	97.24	16.39	96.64	18.03	95.98	19.64
36	97.76	14.79	97.22	16.44	96.62	18.08	95.96	19.70
38	97.75	14.84	97.20	16.50	96.60	18.14	95.93	19.75
40	97.73	14.90	97.18	16.55	96.57	18.19	95.91	19.80
42	97.71	14.95	97.16	16.61	96.55	18.24	95.89	19.86
44	97.69	15.01	97.14	16.66	96.53	18.30	95.86	19.91
46	97.68	15.06	97.12	16.72	96.51	18.35	95.84	19.96
48	97.66	15.12	97.10	16.77	96.49	18.41	95.82	20.02
50	97.64	15.17	97.08	16.83	96.47	18.46	95.79	20.07
52	97.62	15.23	97.06	16.88	96.45	18.51	95.77	20.12
54	97.61	15.28	97.04	16.94	96.42	18.57	95.75	20.18
56	97.59	15.34	97.02	16.99	96.40	18.62	95.72	20.23
58	97.57	15.40	97.00	17.05	96.38	18.68	95.70	20.28
60	97.55	15.45	96.98	17.10	96.36	18.73	95.68	20.34
For (e + f)								
= 0.75	0.74	0.11	0.74	0.12	0.74	0.14	0.73	0.15
= 1.00	0.99	0.15	0.99	0.16	0.98	0.18	0.98	0.20
= 1.25	1.23	0.18	1.23	0.21	1.23	0.23	1.22	0.25

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Minutes	12°		13°		14°		15°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	95.68	20.34	94.94	21.92	94.15	23.47	93.30	25.00
2	95.65	20.39	94.91	21.97	94.12	23.52	93.27	25.05
4	95.63	20.44	94.89	22.02	94.09	23.58	93.24	25.10
6	95.61	20.50	94.86	22.08	94.07	23.63	93.21	25.15
8	95.58	20.55	94.84	22.13	94.04	23.68	93.18	25.20
10	95.56	20.60	94.81	22.18	94.01	23.73	93.16	25.25
12	95.53	20.66	94.79	22.23	93.98	23.78	93.13	25.30
14	95.51	20.71	94.76	22.28	93.95	23.83	93.10	25.35
16	95.49	20.76	94.73	22.34	93.93	23.88	93.07	25.40
18	95.46	20.81	94.71	22.39	93.90	23.93	93.04	25.45
20	95.44	20.87	94.68	22.44	93.87	23.99	93.01	25.50
22	95.41	20.92	94.66	22.49	93.84	24.04	92.98	25.55
24	95.39	20.97	94.63	22.54	93.81	24.09	92.95	25.60
26	95.36	21.03	94.60	22.60	93.79	24.14	92.92	25.65
28	95.34	21.08	94.58	22.65	93.76	24.19	92.89	25.70
30	95.32	21.13	94.55	22.70	93.73	24.24	92.86	25.75
32	95.29	21.18	94.52	22.75	93.70	24.29	92.83	25.80
34	95.27	21.24	94.50	22.80	93.67	24.34	92.80	25.85
36	95.24	21.29	94.47	22.85	93.65	24.39	92.77	25.90
38	95.22	21.34	94.44	22.91	93.62	24.44	92.74	25.95
40	95.19	21.39	94.42	22.96	93.59	24.49	92.71	26.00
42	95.17	21.45	94.39	23.01	93.56	24.55	92.68	26.05
44	95.14	21.50	94.36	23.06	93.53	24.60	92.65	26.10
46	95.12	21.55	94.34	23.11	93.50	24.65	92.62	26.15
48	95.09	21.60	94.31	23.16	93.47	24.70	92.59	26.20
50	95.07	21.66	94.28	23.22	93.45	24.75	92.56	26.25
52	95.04	21.71	94.26	23.27	93.42	24.80	92.53	26.30
54	95.02	21.76	94.23	23.32	93.39	24.85	92.49	26.35
56	94.99	21.81	94.20	23.37	93.36	24.90	92.46	26.40
58	94.97	21.87	94.17	23.42	93.33	24.95	92.43	26.45
60	94.94	21.92	94.15	23.47	93.30	25.00	92.40	26.50
For (c + f)								
= 0.75	0.73	0.16	0.73	0.17	0.73	0.19	0.72	0.20
= 1.00	0.98	0.22	0.97	0.23	0.97	0.25	0.96	0.27
= 1.25	1.22	0.27	1.21	0.29	1.21	0.31	1.20	0.34

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Minutes	16°		17°		18°		19°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	92.40	26.50	91.45	27.96	90.45	29.39	89.40	30.78
2	92.37	26.55	91.42	28.01	90.42	29.44	89.36	30.83
4	92.34	26.59	91.39	28.06	90.38	29.48	89.33	30.87
6	92.31	26.64	91.35	28.10	90.35	29.53	89.29	30.92
8	92.28	26.69	91.32	28.15	90.31	29.58	89.26	30.97
10	92.25	26.74	91.29	28.20	90.28	29.62	89.22	30.01
12	92.22	26.79	91.26	28.25	90.24	29.67	89.18	31.06
14	92.19	26.84	91.22	28.30	90.21	29.72	89.15	31.10
16	92.15	26.89	91.19	28.34	90.18	29.76	89.11	31.15
18	92.12	26.94	91.16	28.39	90.14	29.81	89.08	31.19
20	92.09	26.99	91.12	28.44	90.11	29.86	89.04	31.24
22	92.06	27.04	91.09	28.49	90.07	29.90	89.00	31.28
24	92.03	27.09	91.06	28.54	90.04	29.95	88.96	31.33
26	92.00	27.13	91.02	28.58	90.00	30.00	88.93	31.38
28	91.97	27.18	90.99	28.63	89.97	30.04	88.89	31.42
30	91.93	27.23	90.96	28.68	89.93	30.09	88.86	31.47
32	91.90	27.28	90.92	28.73	89.90	30.14	88.82	31.51
34	91.87	27.33	90.89	28.77	89.86	30.19	88.78	31.56
36	91.84	27.38	90.86	28.82	89.83	30.23	88.75	31.60
38	91.81	27.43	90.82	28.87	89.79	30.28	88.71	31.65
40	91.77	27.48	90.79	28.92	89.76	30.32	88.67	31.69
42	91.74	27.52	90.76	28.96	89.72	30.37	88.64	31.74
44	91.71	27.57	90.72	29.01	89.69	30.41	88.60	31.78
46	91.68	27.62	90.69	29.06	89.65	30.46	88.56	31.83
48	91.65	27.67	90.66	29.11	89.61	30.51	88.53	31.87
50	91.61	27.72	90.62	29.15	89.58	30.55	88.49	31.92
52	91.58	27.77	90.59	29.20	89.54	30.60	88.45	31.96
54	91.55	27.81	90.55	29.25	89.51	30.65	88.41	32.01
56	91.52	27.86	90.52	29.30	89.47	30.69	88.38	32.05
58	91.48	27.91	90.48	29.34	89.44	30.74	88.34	32.09
60	91.45	27.96	90.45	29.39	89.40	30.78	88.30	32.14
For (c + f)								
= 0.75	0.72	0.21	0.72	0.23	0.71	0.24	0.71	0.25
= 1.00	0.86	0.28	0.95	0.30	0.95	0.32	0.94	0.33
= 1.25	1.20	0.35	1.19	0.38	1.19	0.40	1.19	0.42

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Dist.	20°		21°		22°		23°	
	Diff. Elev.	Minutes Hor.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	88.30	32.14	87.16	33.46	85.97	34.73	84.73	35.97
2	88.26	32.18	87.12	33.50	85.93	34.77	84.69	36.01
4	88.23	32.23	87.08	33.54	85.89	34.82	84.65	36.05
6	88.19	32.27	87.04	33.59	85.85	34.86	84.61	36.09
8	88.15	32.32	87.00	33.63	85.80	34.90	84.57	36.13
10	88.11	32.36	86.96	33.67	85.76	34.94	84.52	36.17
12	88.08	32.41	86.92	33.72	85.72	34.98	84.48	36.21
14	88.04	32.45	86.88	33.76	85.68	35.02	84.44	36.25
16	88.00	32.49	86.84	33.80	85.64	35.07	84.40	36.29
18	87.96	32.54	86.80	33.84	85.60	35.11	84.35	36.33
20	87.93	32.58	86.77	33.89	85.56	35.15	84.31	36.37
22	87.89	32.63	86.73	33.93	85.52	35.19	84.27	36.41
24	87.85	32.67	86.69	33.97	85.48	35.23	84.23	36.45
26	87.81	32.72	86.65	34.01	85.44	35.27	84.18	36.49
28	87.77	32.76	86.61	34.06	85.40	35.31	84.14	36.53
30	87.74	32.80	86.57	34.10	85.36	35.36	84.10	36.57
32	87.70	32.85	86.53	34.14	85.31	35.40	84.06	36.61
34	87.66	32.89	86.49	34.18	85.27	35.44	84.01	36.65
36	87.62	32.93	86.45	34.23	85.23	35.48	83.97	36.69
38	87.58	32.98	86.41	34.27	85.19	35.52	83.93	36.73
40	87.54	33.02	86.37	34.31	85.15	35.56	83.89	36.77
42	87.51	33.07	86.33	34.35	85.11	35.60	83.84	36.80
44	87.47	33.11	86.29	34.40	85.07	35.64	83.80	36.84
46	87.43	33.15	86.25	34.44	85.02	35.68	83.76	36.88
48	87.39	33.20	86.21	34.48	84.98	35.72	83.72	36.92
50	87.35	33.24	86.17	34.52	84.94	35.76	83.67	36.96
52	87.31	33.28	86.13	34.57	84.90	35.80	83.63	37.00
54	87.27	33.33	86.09	34.61	84.86	35.85	83.59	37.04
56	87.24	33.37	86.05	34.65	84.82	35.89	83.54	37.08
58	87.20	33.41	86.01	34.69	84.77	35.93	83.50	37.12
60	87.16	33.46	85.97	34.73	84.73	35.97	83.46	37.16
For (c + f)								
= 0.75	0.70	0.26	0.70	0.27	0.69	0.29	0.69	0.30
= 1.00	0.94	0.35	0.93	0.37	0.92	0.38	0.92	0.40
= 1.25	1.17	0.44	1.16	0.46	1.15	0.48	1.15	0.50

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Minutes	24°		25°		26°		27°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	83.46	37.16	82.14	38.30	80.78	39.40	79.39	40.45
2	83.41	37.20	82.09	38.34	80.74	39.44	79.34	40.49
4	83.37	37.23	82.05	38.38	80.69	39.47	79.30	40.52
6	83.33	37.27	82.01	38.41	80.65	39.51	79.25	40.55
8	83.28	37.31	81.96	38.45	80.60	39.54	79.20	40.59
10	83.24	37.35	81.92	38.49	80.55	39.58	79.15	40.62
12	83.20	37.39	81.87	38.53	80.51	39.61	79.11	40.66
14	83.15	37.43	81.83	38.56	80.46	39.65	79.06	40.69
16	83.11	37.47	81.78	38.60	80.41	39.69	79.01	40.72
18	83.07	37.51	81.74	38.64	80.37	39.72	78.96	40.76
20	83.02	37.54	81.69	38.67	80.32	39.76	78.92	40.79
22	82.98	37.58	81.65	38.71	80.28	39.79	78.87	40.82
24	82.93	37.62	81.60	38.75	80.23	39.83	78.82	40.86
26	82.89	37.66	81.56	38.78	80.18	39.86	78.77	40.89
28	82.85	37.70	81.51	38.82	80.14	39.90	78.73	40.92
30	82.80	37.74	81.47	38.86	80.09	39.93	78.68	40.96
32	82.76	37.77	81.42	38.89	80.04	39.97	78.63	40.99
34	82.72	37.81	81.38	38.93	80.00	40.00	78.58	41.02
36	82.67	37.85	81.33	38.97	79.95	40.04	78.54	41.06
38	82.63	37.89	81.28	39.00	79.90	40.07	78.49	41.09
40	82.58	37.93	81.24	39.04	79.86	40.11	78.44	41.12
42	82.54	37.96	81.19	39.08	79.81	40.14	78.39	41.16
44	82.49	38.00	81.15	39.11	79.76	40.18	78.34	41.19
46	82.45	38.04	81.10	39.15	79.72	40.21	78.30	41.22
48	82.41	38.08	81.06	39.18	79.67	40.24	78.25	41.26
50	82.36	38.11	81.01	39.22	79.62	40.28	78.20	41.29
52	82.32	38.15	80.97	39.26	79.58	40.31	78.15	41.32
54	82.27	38.19	80.92	39.29	79.53	40.35	78.10	41.35
56	82.23	38.23	80.87	39.33	79.48	40.38	78.06	41.39
58	82.18	38.26	80.83	39.36	79.44	40.42	78.01	41.42
60	82.14	38.30	80.78	39.40	79.39	40.45	77.96	41.45
For (c + f)								
= 0.75	0.68	0.31	0.68	0.32	0.67	0.33	0.66	0.35
= 1.00	0.91	0.41	0.90	0.43	0.89	0.45	0.89	0.46
= 1.25	1.14	0.52	1.13	0.54	1.12	0.56	1.11	0.58

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Minutes	28°		29°		30°			
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	77.96	41.45	76.50	42.40	75.00	43.30	.....	.....
2	77.91	41.48	76.45	42.43	74.95	43.33	.....	.....
4	77.86	41.52	76.40	42.46	74.90	43.36	.....	.....
6	77.81	41.55	76.35	42.49	74.85	43.39	.....	.....
8	77.77	41.58	76.30	42.53	74.80	43.42	.....	.....
10	77.72	41.61	76.25	42.56	74.75	43.45	.....	.....
12	77.67	41.65	76.20	42.59	74.70	43.47	.....	.....
14	77.62	41.68	76.15	42.62	74.65	43.50	.....	.....
16	77.57	41.71	76.10	42.65	74.60	43.53	.....	.....
18	77.52	41.74	76.05	42.68	74.55	43.56	.....	.....
20	77.48	41.77	76.00	42.71	74.49	43.59	.....	.....
22	77.42	41.81	75.95	42.74	74.44	43.62	.....	.....
24	77.38	41.84	75.90	42.77	74.39	43.65	.....	.....
26	77.33	41.87	75.85	42.80	74.34	43.67	.....	.....
28	77.28	41.90	75.80	42.83	74.29	43.80	.....	.....
30	77.23	41.93	75.75	42.86	74.24	43.73	.....	.....
32	77.18	41.97	75.70	42.89	74.19	43.76	.....	.....
34	77.13	42.00	75.65	42.92	74.14	43.79	.....	.....
36	77.09	42.03	75.60	42.95	74.09	43.82	.....	.....
38	77.04	42.06	75.55	42.98	74.04	43.84	.....	.....
40	76.99	42.09	75.50	43.01	73.99	43.87	.....	.....
42	76.94	42.12	75.45	43.04	73.93	43.90	.....	.....
44	76.89	42.15	75.40	43.07	73.88	43.93	.....	.....
46	76.84	42.19	75.35	43.10	73.83	43.95	.....	.....
48	76.79	42.22	75.30	43.13	73.78	43.98	.....	.....
50	76.74	42.25	75.25	43.16	73.73	44.01	.....	.....
52	76.69	42.28	75.20	43.18	73.68	44.04	.....	.....
54	76.64	42.31	75.15	43.21	73.63	44.07	.....	.....
56	76.59	42.34	75.10	43.24	73.58	44.09	.....	.....
58	76.55	42.37	75.05	43.27	73.52	44.12	.....	.....
60	76.50	42.40	75.00	43.30	73.47	44.15	.....	.....
For $(c+f)$								
$=0.75$	0.66	0.36	0.65	0.37	0.65	0.38	.....	.....
$=1.00$	0.88	0.48	0.87	0.49	0.86	0.51	.....	.....
$=1.25$	1.10	0.60	1.09	0.62	1.08	0.64	.....	.....

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TABLE II.

Logarithms of Numbers.

N.	0	1	2	3	4	5	6	7	8	9	Prop. Parts. 1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5589	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	5	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	5	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
N.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

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LOGARITHMS OF NUMBERS.

N.	0	1	2	3	4	5	6	7	8	9	Prop. Parts. 1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	6	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	6	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	5	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	5	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	5	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	5	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	5	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	5	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	5	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	5	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	5	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	5	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9558	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4
N.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

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TABLE III.

NATURAL SINES AND COSINES.

Natural Sines.

Angle.	0′	10′	20′	30′	40′	50′	60′	Angle.	Prop. Parts for 1′.
0°	.0000 00	.0029 09	.0058 18	.0087 27	.0116 35	.0145 44	.0174 52	89°	2.9
1	.0174 52	.0203 6	.0232 7	.0261 8	.0290 8	.0319 9	.0349 0	88	2.9
2	.0349 0	.0378 1	.0407 1	.0436 2	.0465 3	.0494 3	.0523 4	87	2.9
3	.0523 4	.0552 4	.0581 4	.0610 5	.0639 5	.0668 5	.0697 6	86	2.9
4	.0697 6	.0726 6	.0755 6	.0784 6	.0813 6	.0842 6	.0871 6	85	2.9
5	.0871 6	.0900 5	.0929 5	.0958 5	.0987 4	.1016 4	.1045 3	84	2.9
6	.1045 3	.1074 2	.1103 1	.1132 0	.1160 9	.1189 8	.1218 7	83	2.9
7	.1218 7	.1247 6	.1276 4	.1305 3	.1334	.1363	.1392	82	2.9
8	.1392	.1421	.1449	.1478	.1507	.1536	.1564	81	2.9
9	.1564	.1593	.1622	.1650	.1679	.1708	.1736	80	2.9
10	.1736	.1765	.1794	.1822	.1851	.1880	.1908	79	2.9
11	.1908	.1937	.1965	.1994	.2022	.2051	.2079	78	2.9
12	.2079	.2108	.2136	.2164	.2193	.2221	.2250	77	2.8
13	.2250	.2278	.2306	.2334	.2363	.2391	.2419	76	2.8
14	.2419	.2447	.2476	.2504	.2532	.2560	.2588	75	2.8
15	.2588	.2616	.2644	.2672	.2700	.2728	.2756	74	2.8
16	.2756	.2784	.2812	.2840	.2868	.2896	.2924	73	2.8
17	.2924	.2952	.2979	.3007	.3035	.3062	.3090	72	2.8
18	.3090	.3118	.3145	.3173	.3201	.3228	.3256	71	2.8
19	.3256	.3283	.3311	.3338	.3365	.3393	.3420	70	2.7
20	.3420	.3448	.3475	.3502	.3529	.3557	.3584	69	2.7
21	.3584	.3611	.3638	.3665	.3692	.3719	.3746	68	2.7
22	.3746	.3773	.3800	.3827	.3854	.3881	.3907	67	2.7
23	.3907	.3934	.3961	.3987	.4014	.4041	.4067	66	2.7
24	.4067	.4094	.4120	.4147	.4173	.4200	.4226	65	2.7
25	.4226	.4253	.4279	.4305	.4331	.4358	.4384	64	2.6
26	.4384	.4410	.4436	.4462	.4488	.4514	.4540	63	2.6
27	.4540	.4566	.4592	.4617	.4643	.4669	.4695	62	2.6
28	.4695	.4720	.4746	.4772	.4797	.4823	.4848	61	2.6
29	.4848	.4874	.4899	.4924	.4950	.4975	.5000	60	2.5
30	.5000	.5025	.5050	.5075	.5100	.5125	.5150	59	2.5
31	.5150	.5175	.5200	.5225	.5250	.5275	.5299	58	2.5
32	.5299	.5324	.5348	.5373	.5398	.5422	.5446	57	2.5
33	.5446	.5471	.5495	.5519	.5544	.5568	.5592	56	2.4
34	.5592	.5616	.5640	.5664	.5688	.5712	.5736	55	2.4
35	.5736	.5760	.5783	.5807	.5831	.5854	.5878	54	2.4
36	.5878	.5901	.5925	.5948	.5972	.5995	.6018	53	2.3
37	.6018	.6041	.6065	.6088	.6111	.6134	.6157	52	2.3
38	.6157	.6180	.6202	.6225	.6248	.6271	.6293	51	2.3
39	.6293	.6316	.6338	.6361	.6383	.6406	.6428	50	2.3
40	.6428	.6450	.6472	.6494	.6517	.6539	.6561	49	2.2
41	.6561	.6583	.6604	.6626	.6648	.6670	.6691	48	2.2
42	.6691	.6713	.6734	.6756	.6777	.6799	.6820	47	2.2
43	.6820	.6841	.6862	.6884	.6905	.6926	.6947	46	2.1
44	.6947	.6967	.6988	.7009	.7030	.7050	.7071	45	2.1
	60′	50′	40′	30′	20′	10′	0′	Angle	

Natural Cosines.

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TABLE III
of
NATURAL SINES AND COSINES.
Natural Sines.

Angle.	0′	10′	20′	30′	40′	50′	60′	Angle.	Prop. Parts for 1′.
45°	.7071	.7092	.7112	.7133	.7153	.7173	.7193	44°	2.0
46	.7193	.7214	.7234	.7254	.7274	.7294	.7314	43	2.0
47	.7314	.7333	.7353	.7373	.7392	.7412	.7431	42	2.0
48	.7431	.7451	.7470	.7490	.7509	.7528	.7547	41	1.9
49	.7547	.7566	.7585	.7604	.7623	.7642	.7660	40	1.9
50	.7660	.7679	.7698	.7716	.7735	.7753	.7771	39	1.9
51	.7771	.7790	.7808	.7826	.7844	.7862	.7880	38	1.8
52	.7880	.7898	.7916	.7934	.7951	.7969	.7986	37	1.8
53	.7986	.8004	.8021	.8039	.8056	.8073	.8090	36	1.7
54	.8090	.8107	.8124	.8141	.8158	.8175	.8192	35	1.7
55	.8192	.8208	.8225	.8241	.8258	.8274	.8290	34	1.6
56	.8290	.8307	.8323	.8339	.8355	.8371	.8387	33	1.6
57	.8387	.8403	.8418	.8434	.8450	.8465	.8480	32	1.6
58	.8480	.8496	.8511	.8526	.8542	.8557	.8572	31	1.5
59	.8572	.8587	.8601	.8616	.8631	.8646	.8660	30	1.5
60	.8660	.8675	.8689	.8704	.8718	.8732	.8746	29	1.4
61	.8746	.8760	.8774	.8788	.8802	.8816	.8829	28	1.4
62	.8829	.8843	.8857	.8870	.8884	.8897	.8910	27	1.4
63	.8910	.8923	.8936	.8949	.8962	.8975	.8988	26	1.3
64	.8988	.9001	.9013	.9026	.9038	.9051	.9063	25	1.3
65	.9063	.9075	.9088	.9100	.9112	.9124	.9135	24	1.2
66	.9135	.9147	.9159	.9171	.9182	.9194	.9205	23	1.2
67	.9205	.9216	.9228	.9239	.9250	.9261	.9272	22	1.1
68	.9272	.9283	.9293	.9304	.9315	.9325	.9336	21	1.1
69	.9336	.9346	.9356	.9367	.9377	.9387	.9397	20	1.0
70	.9397	.9407	.9417	.9426	.9436	.9446	.9455	19	1.0
71	.9455	.9465	.9474	.9483	.9492	.9502	.9511	18	0.9
72	.9511	.9520	.9528	.9537	.9546	.9555	.9563	17	0.9
73	.9563	.9572	.9580	.9588	.9596	.9605	.9613	16	0.8
74	.9613	.9621	.9628	.9636	.9644	.9652	.9659	15	0.8
75	.9659	.9667	.9674	.9681	.9689	.9696	.9703	14	0.7
76	.9703	.9710	.9717	.9724	.9730	.9737	.9744	13	0.7
77	.9744	.9750	.9757	.9763	.9769	.9775	.9781	12	0.6
78	.9781	.9787	.9793	.9799	.9805	.9811	.9816	11	0.6
79	.9816	.9822	.9827	.9833	.9838	.9843	.9848	10	0.5
80	.9848	.9853	.9858	.9863	.9868	.9872	.9877	9	0.5
81	.9877	.9881	.9886	.9890	.9894	.9899	.9903	8	0.4
82	.9903	.9907	.9911	.9914	.9918	.9922	.9925	7	0.4
83	.9925	.9929	.9932	.9936	.9939	.9942	.9945	6	0.3
84	.9945	.9948	.9951	.9954	.9957	.9959	.9962	5	0.3
85	.9962	.9964	.9967	.9969	.9971	.9974	.9976	4	0.2
86	.9976	.9978	.9980	.9981	.9983	.9985	.9986	3	0.2
87	.9986	.9988	.9989	.9990	.9992	.9993	.9994	2	0.1
88	.9994	.9995	.9996	.9997	.9997	.9998	.9998	1	0.1
89	.9998	.9999	.9999	1.0000	1.0000	1.0000	1.0000	0	0.0
	60′	50′	40′	30′	20′	10′	0′	Angle.	

Natural Cosines.

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EXPLANATION OF TABLE III.

The left hand column and top horizontal line show angles in degrees and multiples of 10 minutes, whose natural sines appear in the second to eighth columns. For example: The sine of 40° 10′ is .6450. The second column from the right and the bottom line, in the same way, show the angles whose cosines are correspondingly in the table. For example: the cosine of 59° 40′ is .5050.

The right hand column headed "*prop. parts for 1′*," shows the change in the *natural functions* (sine or cosine) for each change of 1′ of the angle, and is used to find the value of the function when the number of minutes in the given angle is not a multiple of ten. For example, required the sine and the cosine of 30° 16′.

The sine of 30° 10′ is. 5025; the proportional part for 1′ (found at the right end of the same line) is 2.5. Hence for 6′ the proportional part = 2.5 × 6 = 15; 5025 + 15 = .5040 natural sine of 30° 16′.

The cosine of 30° 10′ = .8646. The proportional part for 1′ is 1.5. Hence for 6′ it is 6 × 1.5 = 9; 8646 — 9 = .8637 natural cosine 30° 16′. (The 9 is subtracted because the cosine decreases as the angle increases as shown in the table.)

To find from the table the tangent of an angle divide its sine by its cosine; *to find the cotangent* divide unity by the tangent.

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The sine of an angle is the opposite side divided by the hypotenuse of the right angled triangle; the cosine is the adjacent side divided by the hypotenuse; the tangent is the opposite side divided by the adjacent side. (See figure 98 a).

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